





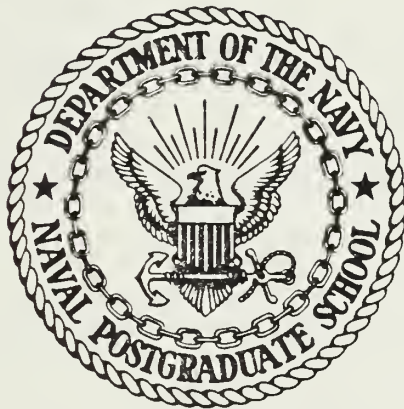






# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

DESIGN AND CONSTRUCTION OF A COMPUTER  
CONTROLLED MICROTHERMOCOUPLE PROBE  
FOR THE STUDY OF BUOYANT JETS

by

Ronald John Matoushek

September 1984

Thesis Advisor:

William G. Culbreth

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Design and Construction of a  
Computer Controlled Microthermocouple  
Probe for the Study of Buoyant Jets

by

Ronald John Matoushek  
Lieutenant Commander, United States Navy  
B.S.E.E., Purdue University, 1974

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# ABSTRACT

A computer-aided data acquisition system was developed and a microthermocouple probe constructed to obtain thermal distributions in turbulent buoyant jets exposed to a cross-flowing ambient fluid. The system performed high speed temperature measurements as a microthermocouple probe was automatically traversed through a sequence of preprogrammed positions under the control of a microcomputer. Operability of the apparatus was demonstrated by measuring temperature distributions in planes perpendicular to the streamwise axis of jets from which contour plots of temperature were generated. Using temperature distributions along with velocity distributions allow buoyant jet characteristics to be computed, including the entrainment rate of ambient fluid, jet trajectory, and heat transfer to the ambient. The experimental technique is discussed and temperature contour plots for a jet at various planes are presented.

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## NOMENCLATURE

$A_{ij}$	Incremental Cross-Sectional Area in the Temperature Matrix
$B$	Jet Half-width
$b$	Normalized Jet Half-width
$c_p$	Specific Heat
$D$	Diameter of the Jet at the Nozzle
$D_{AB}$	Binary Mass Diffusion Coefficient
$F$	Densiometric Froude Number
$g$	Acceleration of Gravity
$\dot{Q}$	Heat Transfer Rate from the Jet to the Ambient Fluid
$R$	Ambient-to-Nozzle Flow Ratio
$R_a$	Length of the Probe Arm
$r$	Radial Distance from the Center of the Jet
$r_p$	Length of the Probe
$S$	Schmidt Number
$s$	Streamwise Coordinate Along the Jet Centerline
$T$	Normalized Jet Temperature
$T_a$	Ambient Fluid Temperature
$T_{ij}$	Jet Temperature Within the Temperature Matrix
$T_m$	Centerline Jet Temperature
$T_n$	Nozzle Temperature
$T_p$	Jet Temperature As Measured by the Probe
$T(r)$	Temperature Within the Jet at a Radial Distance (r) from its Center

$U_m$	Centerline Velocity of the Jet at the Nozzle
$U_o$	Discharge Velocity of the Jet
$U(r)$	Velocity within the Jet at a Radial Distance "r" from its Center
$U_{ij}$	Jet Velocities Corresponding to Locations within the Temperature Matrix
$u$	Normalized Centerline Velocity
$\alpha$	Entrainment Coefficient; Offset Angle of the Probe Arm
$\beta$	Offset Angle of the Probe Mounting Bracket
$\gamma$	Probe Angle of Deflection from Horizontal
$\theta$	Local Angle of Inclination from Horizontal of the Jet Streamwise Axis
$\lambda$	Spreading Ratio
$\nu$	Kinematic Viscosity
$\rho$	Density of the Jet Fluid
$\rho_a$	Density of the Ambient Fluid
$\rho_{ao}$	Density of the Ambient Fluid at the Nozzle Exit
$\rho_m$	Density of the Jet at Centerline
$\rho_{mo}$	Centerline Density of the Jet at the Nozzle
$\phi$	Angle of Inclination of the Data Plane from Horizontal



## I. INTRODUCTION

Buoyant jets are very common in nature. We see them in the form of exhaust gases emitted from smoke stacks of refineries, mills and ships. We see them in the form of heated waste water expelled into the sea from power plants and from the main propulsion condensers in steam driven ships and submarines. It is no wonder that the fluid mechanics and heat transfer characteristics of buoyant jets have been of interest to environmental, civil and mechanical engineers for decades. To evaluate their ecological impact, and of most recent interest, to harness buoyant jets as a means of detecting military targets and guiding weapons, it is necessary to develop models which accurately predict their trajectory and decay.

Most studies to date have dealt with buoyant jets rising through a quiescent ambient fluid; however, in nature most problems involve flowing ambient fluids. Relatively little experimental work has been done with buoyant jets in cross-flow and, according to Hilder [Ref. 1], the trajectories of jets and the entrainment rates of ambient fluid predicted from previous work do not agree well with one another. Most mathematical models of buoyant jets in crossflow assume Gaussian profiles for velocity and temperature. Nickodem [Ref. 2] has shown through experiments that in fact, the

Gaussian profiles of velocity are altered by crossflow. This leads one to suspect that the same may be true for the temperature profiles.

The objective of this work was to develop a system to thermally map a buoyant jet in crossflow. Then, by measuring both velocity and temperature distributions, improved computations of entrainment, trajectory and heat transfer characteristics of jets can be made thereby giving rise to more accurate models.

## II. BUOYANT JETS DISCHARGED TO A CROSSFLOW

### A. PROPERTIES OF BUOYANT JETS

A buoyant jet is characterized by a momentum and a density differential between the jet and its surrounding ambient resulting from a variation in temperature and/or fluid concentrations. Therefore, fluid motion in the jet is governed by both inertial and buoyant forces. The non-dimensional ratio of these forces, known as the densimetric Froude number, provides an important quantitative measurement of jet characteristics and is shown below.

$$F = \frac{U_o^2}{gD(\rho_a - \rho_o)/\rho_o}$$

where  $U_o$  is the jet's discharge velocity,  $g$  is the acceleration of gravity,  $D$  is the discharge diameter of the jet,  $\rho_a$  is the density of the crossflowing ambient and  $\rho_o$  is the density of the jet fluid at its point of discharge.

The Gaussian velocity and temperature profiles assumed by most models of buoyant jets are very similar. Velocity behavior is given by:

$$U(r) = U_m \exp(-r^2/B^2)$$

where  $U_m$  is the centerline velocity,  $r$  is the independent variable and a radial distance from the centerline of the

jet, and  $B$  is defined as nominal jet halfwidth. As  $r$  approaches  $B$ , velocity decays to  $(1/e)U_m$  [Ref. 3]. Similarly, temperature behavior is given by:

$$T(r) = T_m \exp(-r^2/\lambda^2 B^2)$$

where  $T_m$  is the centerline temperature,  $r$  and  $B$  are defined the same as above and  $\lambda$ , a spreading ratio, is the inverse of the turbulent Schmidt number ( $S$ ).  $S$  is defined as the ratio of the molecular momentum and mass diffusivities and is equal to  $\nu/D_{AB}$  where  $\nu$  is the kinematic viscosity and  $D_{AB}$  is the binary mass diffusion coefficient associated with substances  $A$  and  $B$  [Ref. 4]. Although  $\lambda$  varies inversely with the Froude number, the change is very slight, and in the case where substances  $A$  and  $B$  are both water,  $\lambda$  is slightly greater than 1. Hirst [Ref. 3] found  $\lambda$  to vary between 1.16 at  $F = 0$  to 1.11 at  $F = \text{infinity}$ . The net effect then, is a more gradual temperature decay than was found with velocity.

Most buoyant jet models consider the entrainment of the ambient fluid into the jet and are based on relevant conservation equations of mass, momentum and energy. In conservation of mass, the downstream change in total mass of the jet is equated to the mass of the entrained fluid. The conservation of momentum must consider both vertical and horizontal contributions. Changes in vertical momentum are equated to the buoyant forces while changes in the horizontal



momentum of the jet are equated to the horizontal momentum of the entrained fluid. The conservation of energy involves energy changes resulting from variations in the ambient temperature as caused by the jet. Hilder [Ref. 1] developed the following governing equations in non-dimensional differential form.

$$\text{CONTINUITY} \quad \frac{d}{ds}(u_m b^2) = 2ab[|u_m - R \cos \theta| + a_3 R \sin \theta]$$

$$\text{HORIZONTAL MOMENTUM} \quad \frac{d}{ds}(u_m^2 b^2 \cos \theta) = 4Rab[|u_m - R \cos \theta| + a_3 R \sin \theta]$$

$$\text{VERTICAL MOMENTUM} \quad \frac{d}{ds}(u_m^2 b^2 \sin \theta) = \left( \frac{\rho_a - \rho_m}{\rho_{ao} - \rho_{mo}} \right) \cdot \frac{2\lambda^2 b^2}{F^2}$$

$$\text{ENERGY} \quad \frac{d}{ds}\left(u_m T \cdot \frac{\lambda^2 b^2}{(\lambda^2 + 1)}\right) = \frac{\Delta t_a}{ds}\{u_m b^2\}$$

## B. FLOW REGIMES

The jet passes through several regimes as it travels from the nozzle through the ambient. The three regions most frequently referred to are shown in Figure 1. They are the zone of flow establishment, the zone of established flow and the far-field zone [Ref. 3]. In the zone of flow establishment, the velocity and turbulence profiles transform from the conditions within the nozzle to a free turbulent flow condition. It is in this region that the jet begins to mix with the ambient fluid; however, the flow is still more

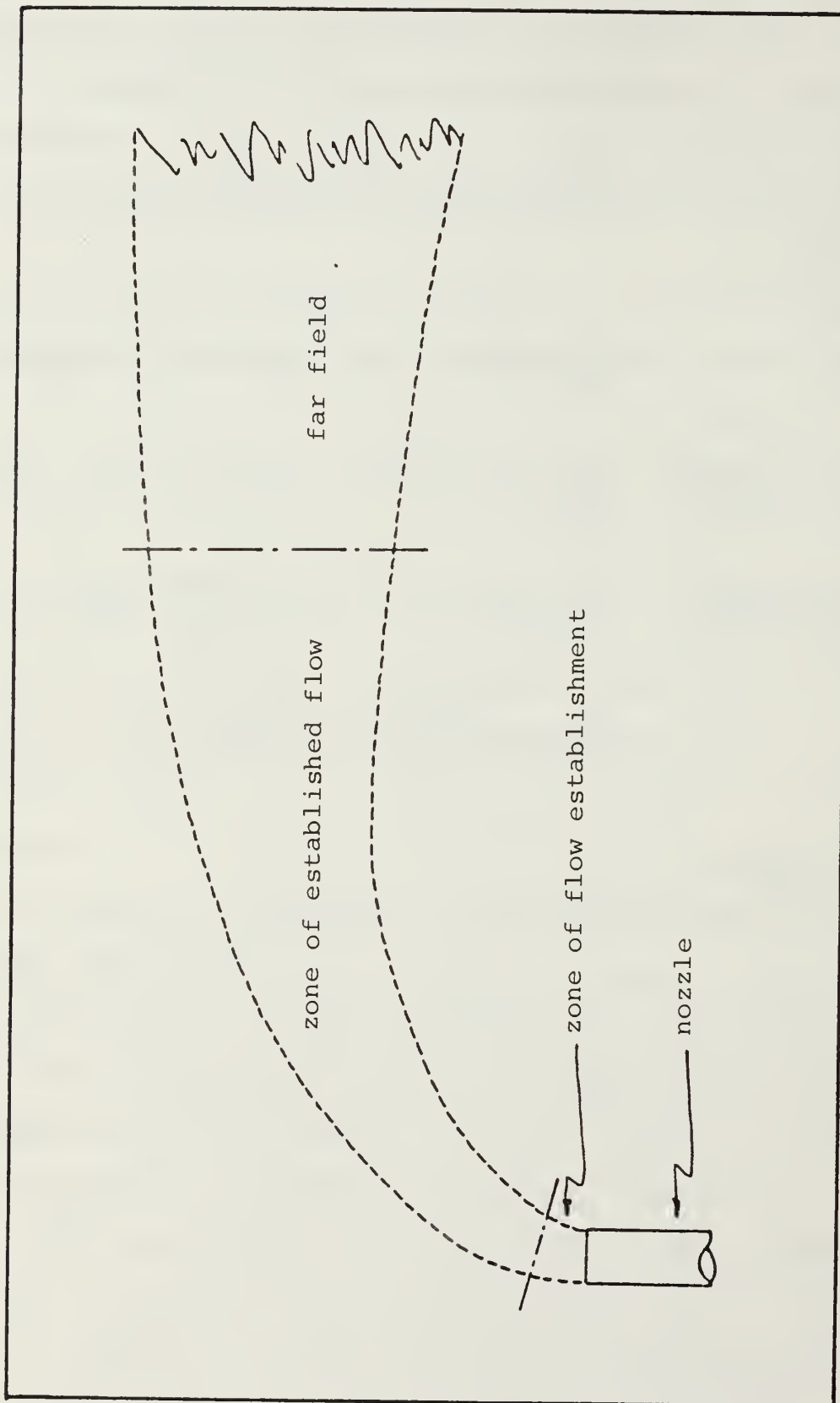


Figure 1. Typical Flow Regions in a Buoyant Jet

strongly influenced by the nozzle discharge conditions than by the ambient. When the turbulent mixing has reached the centerline of the jet, the zone of established flow is said to begin. In this region, the profiles have assumed their free turbulent shapes. Now the flow is governed by the jets' momentum and buoyancy as well as by the condition of the crossflow. The far field zone is defined as that region in which jet momentum is depleted and the jet fluid is convected and diffused by the ambient currents and turbulence.

### C. EFFECTS OF CROSSFLOW

At the immediate exit of a cylindrical nozzle, a vertically discharged buoyant jet has a nearly uniform velocity distribution and has the same cross-sectional shape as the nozzle itself. The velocity gradient between the jet and the crossflowing ambient creates longitudinal shear stresses at the jet's sides, a positive pressure region immediately upstream and a negative pressure region immediately downstream of the jet. This results in the deflection of the jet's trajectory in the downstream direction (Figure 2), the creation of counterrotating vortices at the jet's outer edges and the deformation of the original circular cross-sectional shape into the form of a kidney. As the streamwise axis of the jet approaches the direction of the crossflow, these effects become progressively less pronounced.

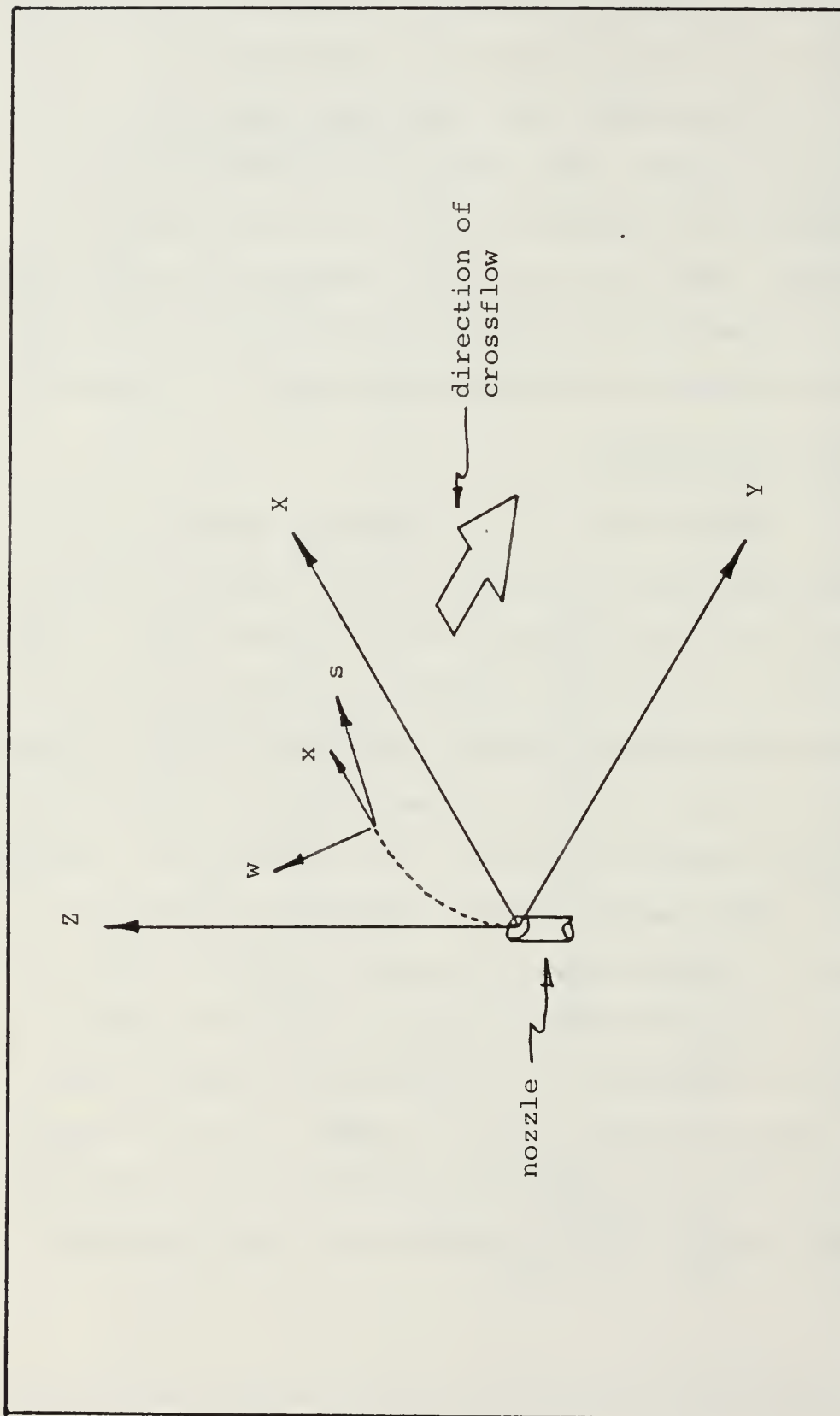


Figure 2. Coordinate System for a Buoyant Jet



### III. EXPERIMENTAL APPARATUS

#### A. SYSTEM OVERVIEW

A surplus milling machine was configured with synchronous drive motors interfaced with a microcomputer that automatically positioned its bed. It was used as a three-dimensional positioning platform in the same manner as in the laser Doppler velocimetry work undertaken by Nickodem [Ref. 2]. The milling machine was placed adjacent to a rectangular plexiglass flume through which the crossflowing ambient fluid flowed. A vertical nozzle was installed in the base of the flume to provide the jet. A temperature probe was suspended through an opening in the top of the flume above the nozzle by an arm attached to a base mounted on the milling machine bed as shown in Figure 3. As the probe was automatically traversed through a series of preprogrammed positions across the jet, temperature data was automatically sensed and stored at high speeds by the computer.

#### B. CROSSFLOW SYSTEM

As illustrated in Figure 4, the crossflow circulation pump took water from the cylindrical 248.8 l (65.7 gal) reservoir shown in Figure 5 and discharged through 5.076 cm (2 in) diameter tubing into a cylindrical flow settling chamber 30.46 cm (12 in) in diameter and 60.91 cm (24 in) tall located within the 60.91 cm  $\times$  60.91 cm  $\times$  88.83 cm

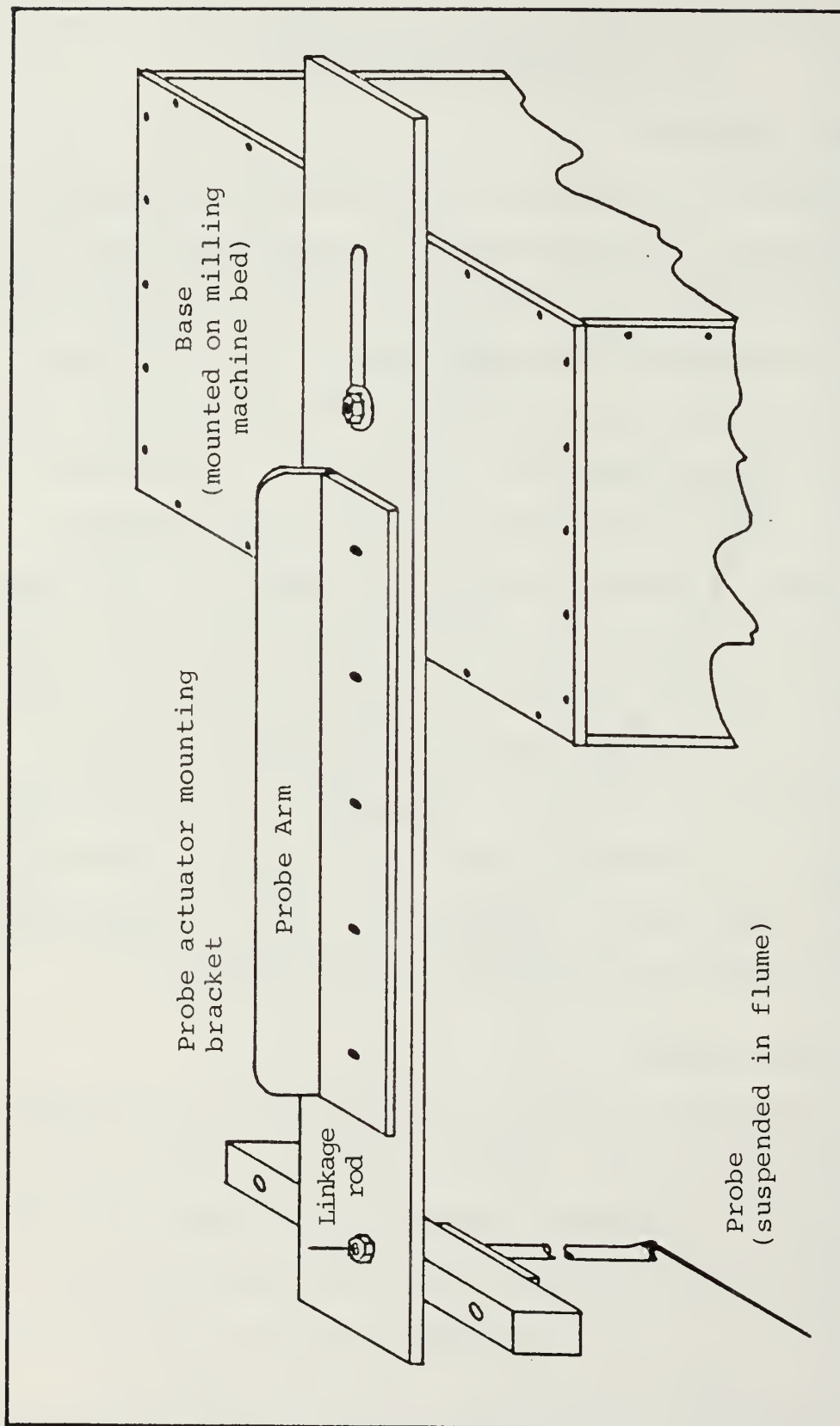


Figure 3. Probe and Traversing Mechanism

- A. Jet flow pump reservoir  
 B. Jet flow pump  
 C. Jet flow pump recirc  
 D. Head tank  
 E. Head tank overflow  
 F. Rotometer  
 G. Make-up  
 H. Dye injection system  
 I. Heater  
 J. Thermocouple junction  
 K. Jet flow control valve  
 L. Nozzle  
 M. Crossflow pump reservoir  
 N. Crossflow pump  
 O. Fill/Make-up  
 P. Inlet chamber  
 Q. Flow straighteners  
 R. Flow settling chamber  
 S. Crossflow recirc  
 T. Cooler  
 U. Flume  
 V. Drain

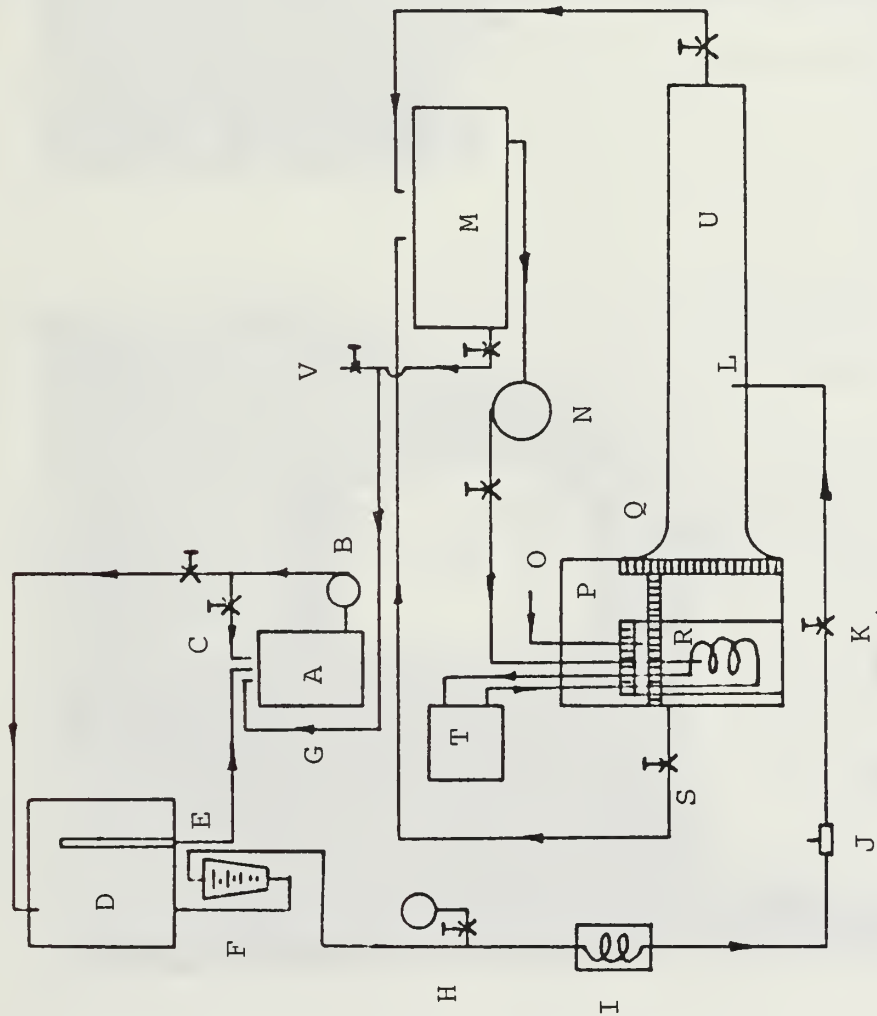


Figure 4. Crossflow and Jet Loop Piping Diagram

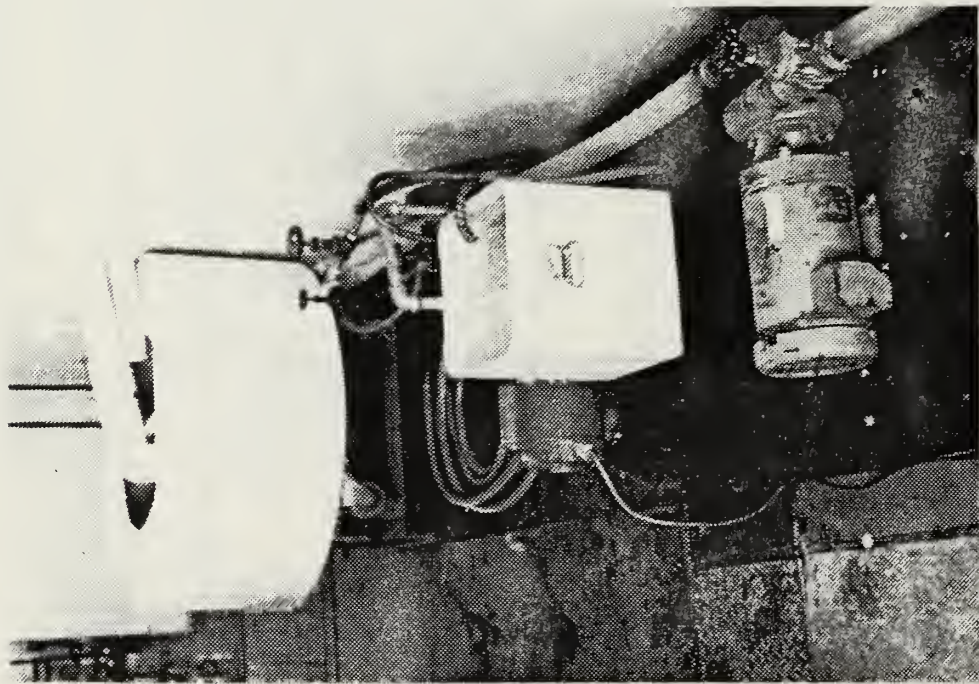


Figure 5. Flume Circulation and  
Jet Loop Pumps

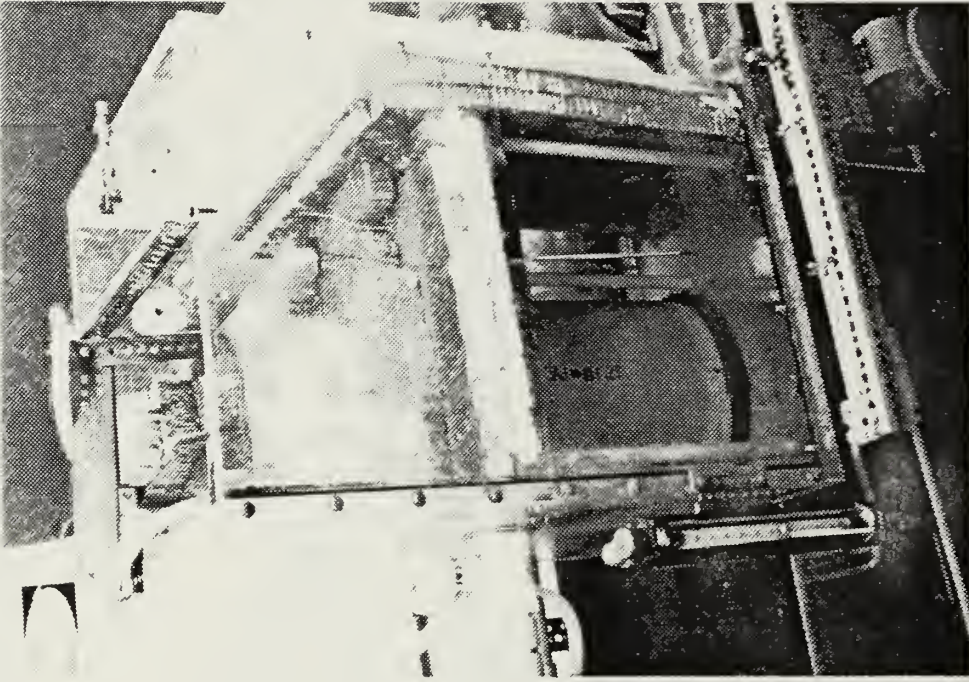


Figure 6. Inlet and Flow  
Settling Chambers



(24 in  $\times$  24 in  $\times$  35 in) inlet chamber shown in Figure 6. The settling chamber was sealed at its bottom so that the water spilled from its top into the inlet chamber through honeycombed flow straighteners to reduce turbulence and evenly disperse the flow. To further reduce turbulence, the flow was broken by another stack of honeycombed flow straighteners and a layer of fiberglass filter material located immediately above the normal operating water level. The flow next entered a 24.4 cm  $\times$  32.39 cm  $\times$  182.9 cm (9.625 in  $\times$  12.75 in  $\times$  72 in) flume shown in Figure 7 through a vertical section of the same honeycombed material mentioned above. To avoid inadvertent spillage over the sides of the flume during system start-up, a 5.076 cm (2 in) diameter overflow pipe was located in the inlet chamber. During normal operation, a gate valve in this piping was closed. The flow left the flume through a 7.614 cm (3 in) diameter pipe at its end and re-entered the crossflow circulation pump reservoir. A gate valve located in this piping and shown in Figure 8 was used to regulate the water level and flow velocity in the flume. The optimum adjustment of this valve was determined by trial and error to be closed two turns from its fully open position. Either a globe or ball valve would have been more appropriate for this purpose; however, neither was readily available, so the gate valve was used. The bracket shown at the base of the flume in Figure 8 maintained alignment between the flume and the milling machine. The water

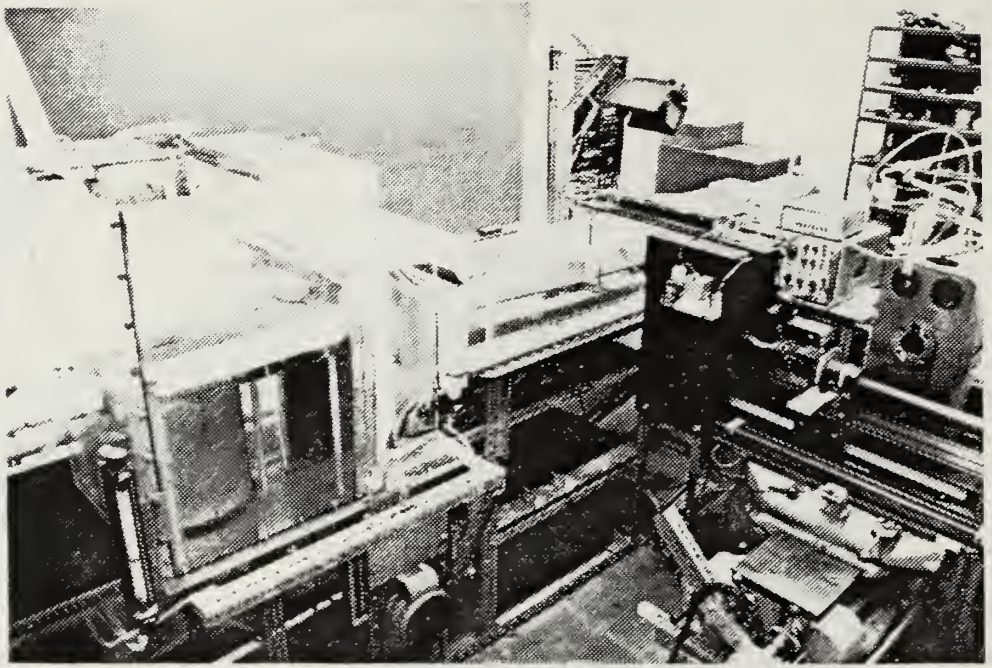


Figure 7. Flume Arrangement

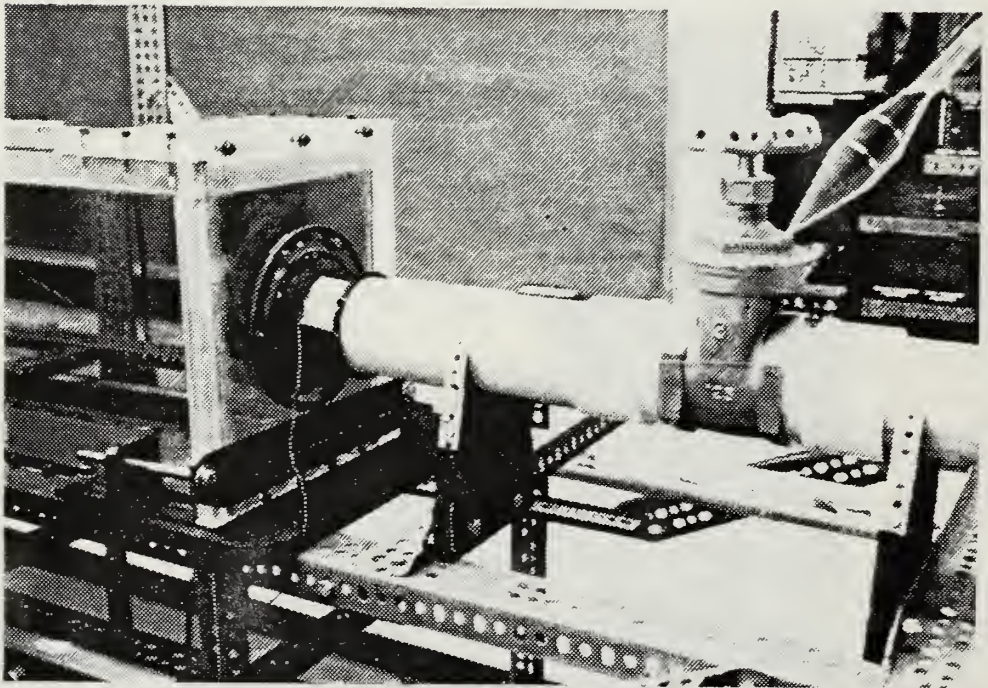


Figure 8. Flume Discharge Piping



in the flume was gradually heated by repetitive circulation through the crossflow pump and by the addition of the heated water from the jet. To maintain a constant temperature crossflow, cooling water from a refrigerated bath shown in Figure 9 was circulated through a coil of 1.269 cm (.5 in) diameter copper tubing located in the flow settling chamber. Also, fresh water was added at the flow settling chamber as an equal amount was drained from the crossflow pump reservoir through a 1.269 cm (.5 in) diameter pipe. Cross-flow temperature was monitored by a Type-T thermocouple located in the inlet chamber.

### C. JET SYSTEM

In reference to Figures 4 and 5, the jet flow pump circulated water from a rectangular 26.27 l (6.94 gal) reservoir and discharged through 1.26 cm (.5 in) diameter tubing to a 33.0 cm × 50.8 cm × 54.6 cm (13 in × 20 in × 21.5 in) head tank (Figure 10). The amount of flow to the head tank was regulated by a globe valve. Due to a low flow rate to the head tank, water was also recirculated back to the reservoir in order to maintain sufficient flow through the jet pump to prevent overheating it. A constant water level was maintained in the head tank by a stand pipe which allowed overflow back to the reservoir. Sufficient flow into the tank was maintained to make sure that it slightly overflowed continuously. Water drained from the bottom of the head tank through 1.26 cm (.5 in) diameter tubing and passed



Figure 9. Refrigerated Bath

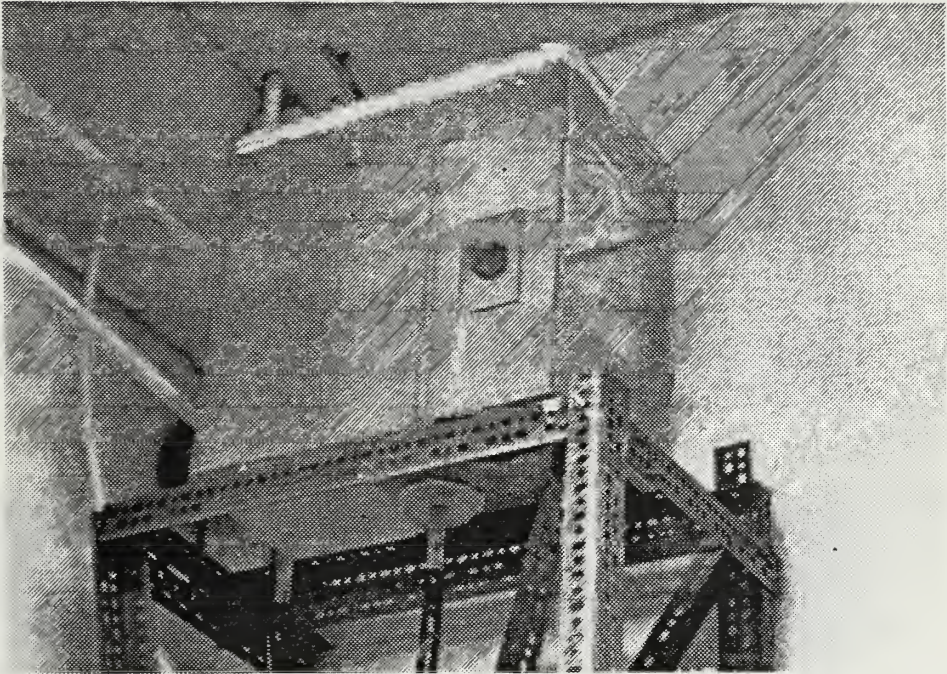


Figure 10. Head Tank



through a rotometer, a .95 cm (.375 in) tubing reducer, a dye injection system (Figure 11), a water heater (Figure 12) consisting of approximately 6.09 m (20 ft) of .95 cm (.375 in) diameter copper tubing coiled in a heated bath and finally a 7.144 cm (.28125 in) nozzle which discharged into the bottom of the flume. Flow was controlled by pinching the tubing between the heater and the nozzle with surgical clamps. Drainage from the crossflow reservoir discussed in Section III.B was used to replenish the jet reservoir. The dye injection system, used in photographing the jet, was located approximately 8.23 m (27 ft) upstream of the nozzle to minimize any disturbance to the jet that it might have caused. The majority of this distance was taken up by the heating coil mentioned above. The vertical distance between the top of the stand pipe in the head tank and the tip of the nozzle in the flume was 2.2 m (86.5 in) which equated to 21.56 KPa (3.127 psig). Jet flow temperature was monitored by a Type-T thermocouple located within the jet flow tubing approximately 1.167 m (46 in) from the nozzle.

#### D. TEMPERATURE PROBE

Measuring temperatures in a buoyant jet with a thermocouple is intrusive. To reduce the probability of distorting results, steps were taken to minimize the cross-sectional area of the temperature measuring device as seen by the flow of the jet. A .0254 mm (.001 in) diameter Type-E micro-thermocouple was selected. The suspension device for the

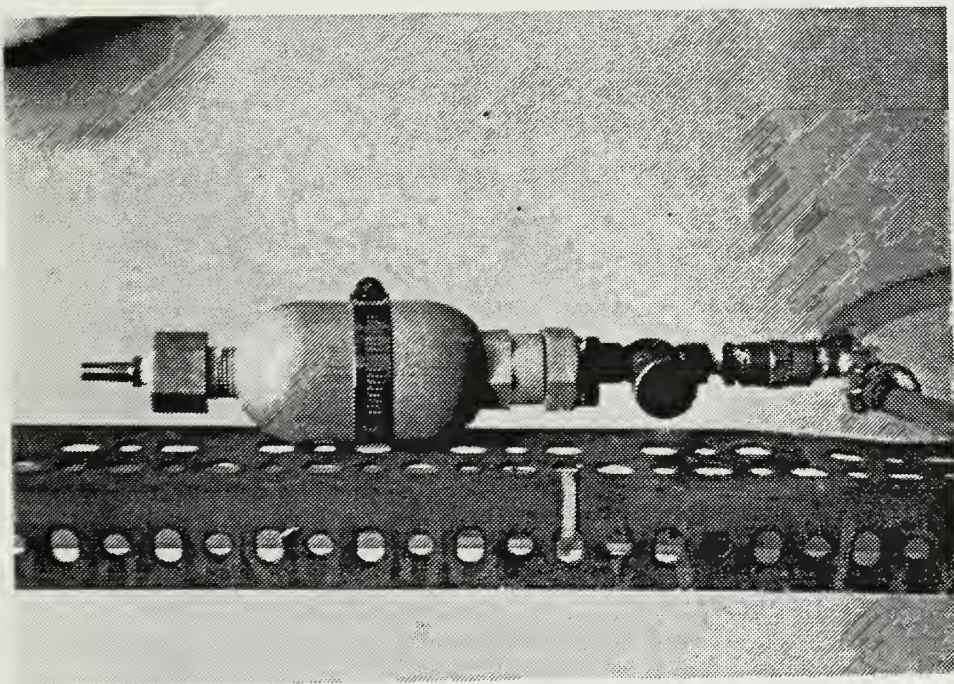


Figure 11. Dye Injection System

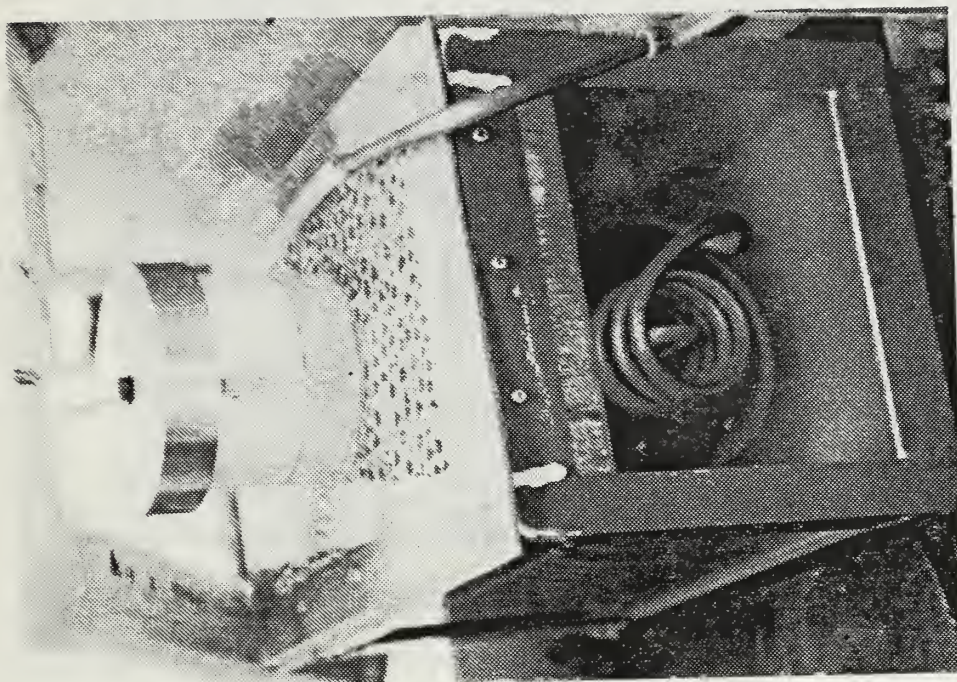


Figure 12. Jet Heater



microthermocouple had to be rigid and have a small cross-sectional area, for reasons discussed above, as well as be an electrical insulator to prevent interference with the thermocouple performance. A glass annulus approximately 1.45 mm (.057 in) in diameter and 11.27 cm (4.4375 in) in length was chosen. One lead of the thermocouple was threaded through the annulus and the other was glued with a fast drying modelers' glue along the outer surface, allowing the microthermocouple junction to protrude slightly from the tip of the annulus. The leads at the opposite end of the annulus were welded to .0762 mm (.003 in) diameter wire which subsequently was connected to 28 AWG extension wire to the computer. The annulus was mounted as shown in Figure 13. Henceforth, this device will be referred to as the probe.

#### E. PROBE ACTUATOR ASSEMBLY

The cross sectional area of the probe as seen by the jet was further reduced by orienting the probe tangentially to the trajectory of the jet as shown in Figure 14. This photograph indicated that the probe created no noticeable interference with the jet hydrodynamics. Probe orientation was accomplished by the linkage assembly shown in Figure 15. The fixed end of the probe was hinged to a streamlined tube 23.495 cm (9.25 in) long with a maximum width and depth, as seen by the jet, of 3.175 mm (.125 in) and 6.35 mm (.25 in) respectively. It was rigidly connected to the mounting



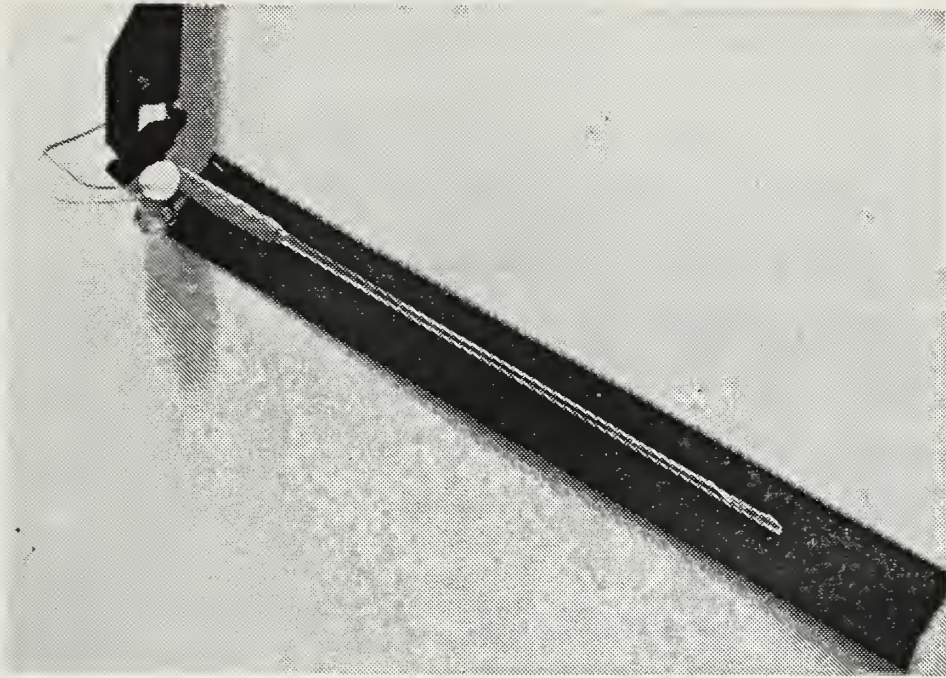


Figure 13. Probe Profile

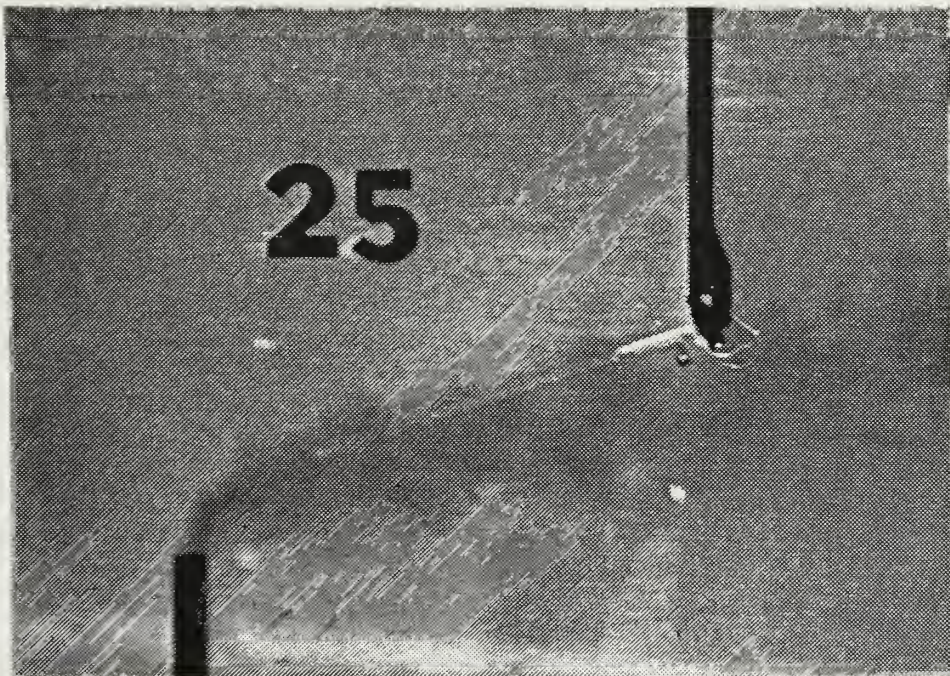


Figure 14. Probe in Jet

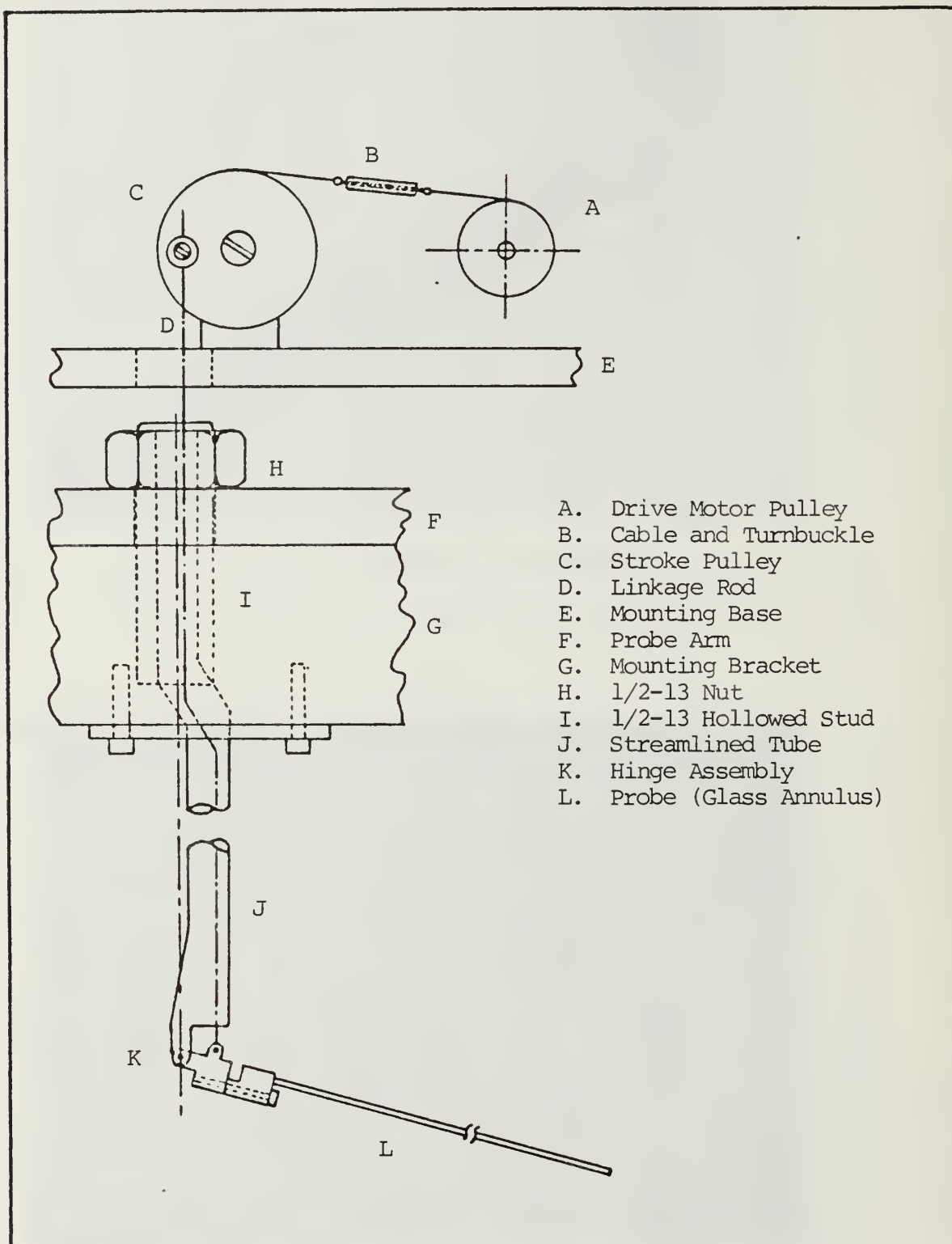


Figure 15. Probe Assembly Linkage



bracket as shown in Figure 15 which was connected to the probe arm shown in Figure 3 by a single stud which allowed pivoting of the probe from side-to-side. The stud was also hollowed so that a linkage rod could extend from the hinge assembly through the tube and stud to a stroking pulley which was rotated by a small motor. The hinge assembly and the stroking pulley were spring loaded to reduce hysteresis. As shown in Figures 16 and 17, the 1.5 VDC motor, geared to one rpm, was directly coupled to a potentiometer as well as the drive pulley. The potentiometer was configured in a voltage divider such that the amount of motor rotation, and ultimately the degree of probe deflection, was proportional to the potential difference sensed across the potentiometer. Limit switches were installed at the stroke pulley as shown in Figures 16 and 18 to prevent damage to the linkage assembly due to over-rotation.

#### F. MICROCOMPUTER INTERFACE

The data collection process consisted of adjusting the probe angle of deflection, traversing the three-dimensional positioning platform and measuring temperature profiles. All of the mechanisms which controlled these events were interfaced to an HP-9826 computer shown in Figure 19 through an HP-6942A multiprogrammer which performed high speed analog-to-digital conversions and ultimately provided control signals to govern relays within the system. Refer to MAIN\_T in Appendix B for the microcomputer software which directed this process.

- A. 10 k $\Omega$  Linear One-turn Potentiometer
- B. 1.5 VDC Drive Motor
- C. Reduction Gearing (1 rmp out)
- D. Drive Motor Pulley
- E. Turnbuckle and Cable
- F. Stroke Pulley
- G. Limit Switches
- H. Loading Spring
- I. 10 Terminal Buss
- J. Type MRRICDL Relays
- K. 2 Terminal Buss

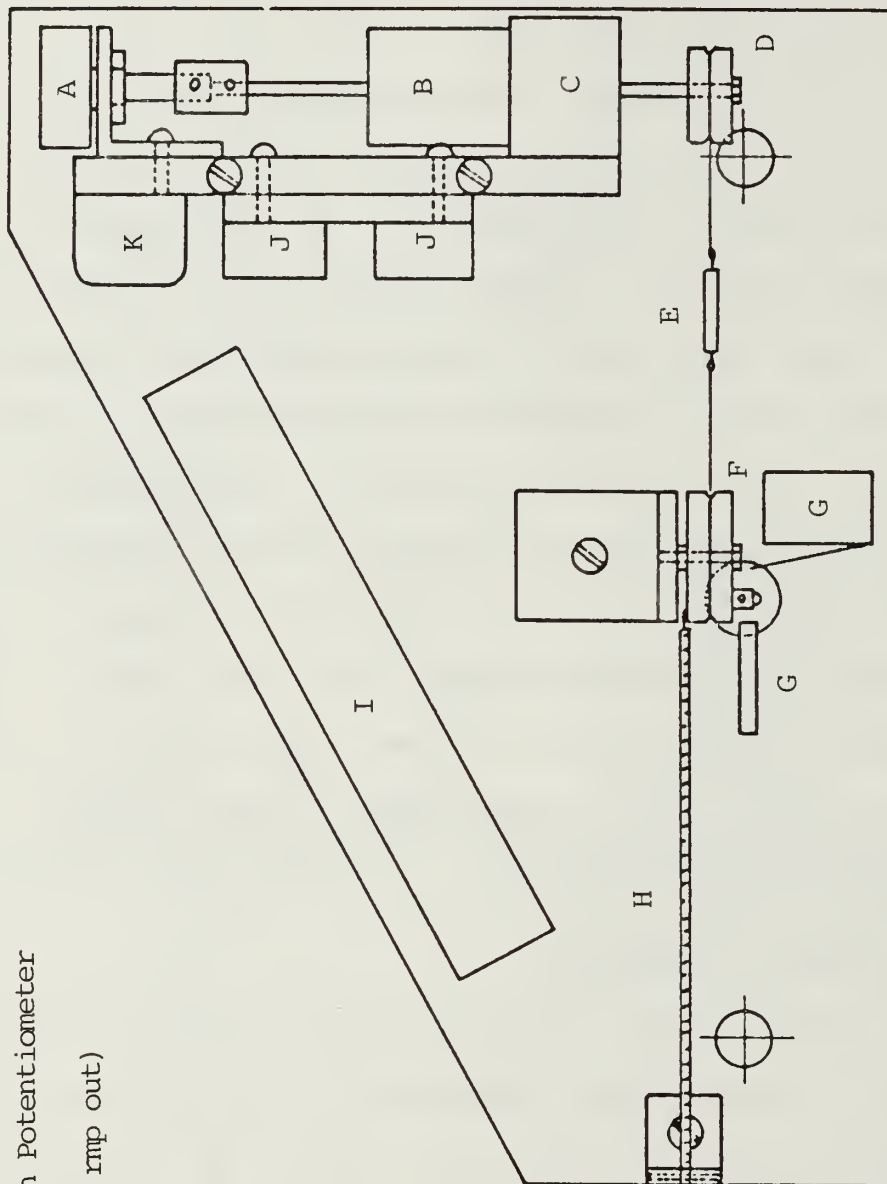


Figure 16. Probe Actuator Assembly

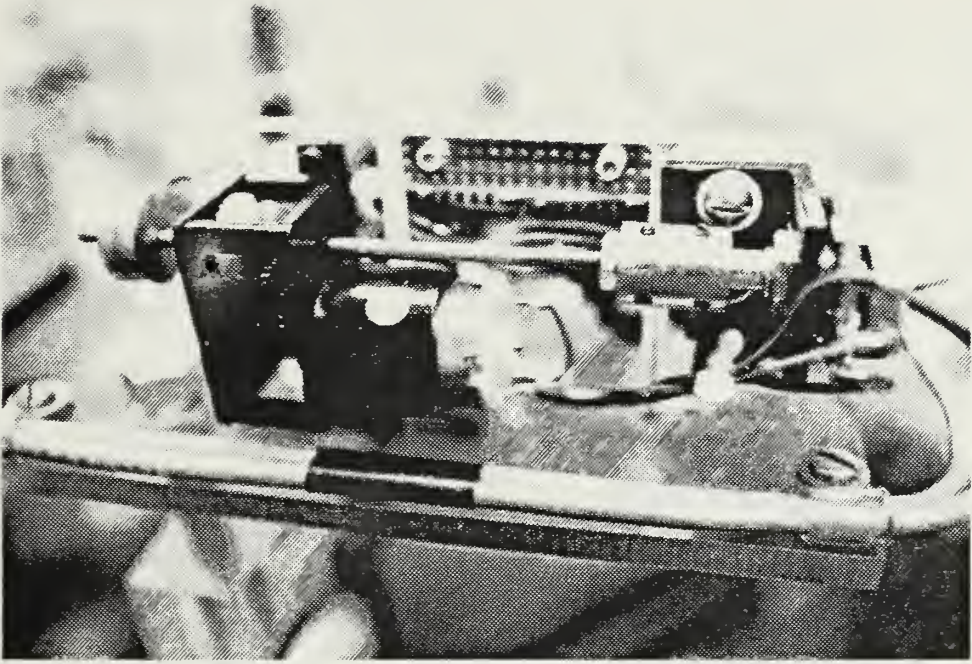


Figure 17. Probe Actuator Motor-Potentiometer Arrangement

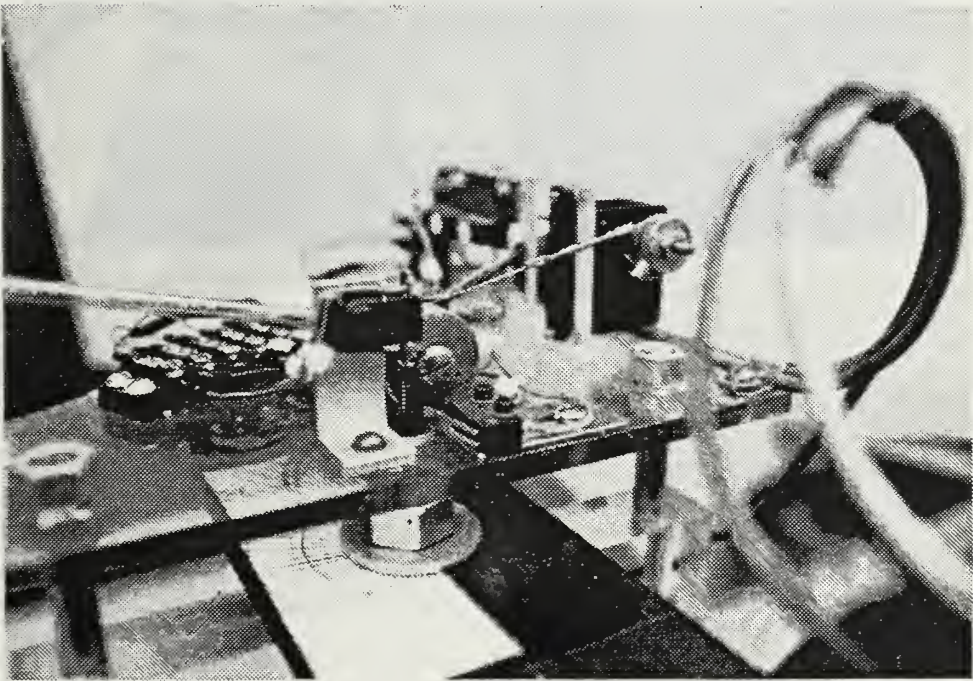


Figure 18. Probe Actuator



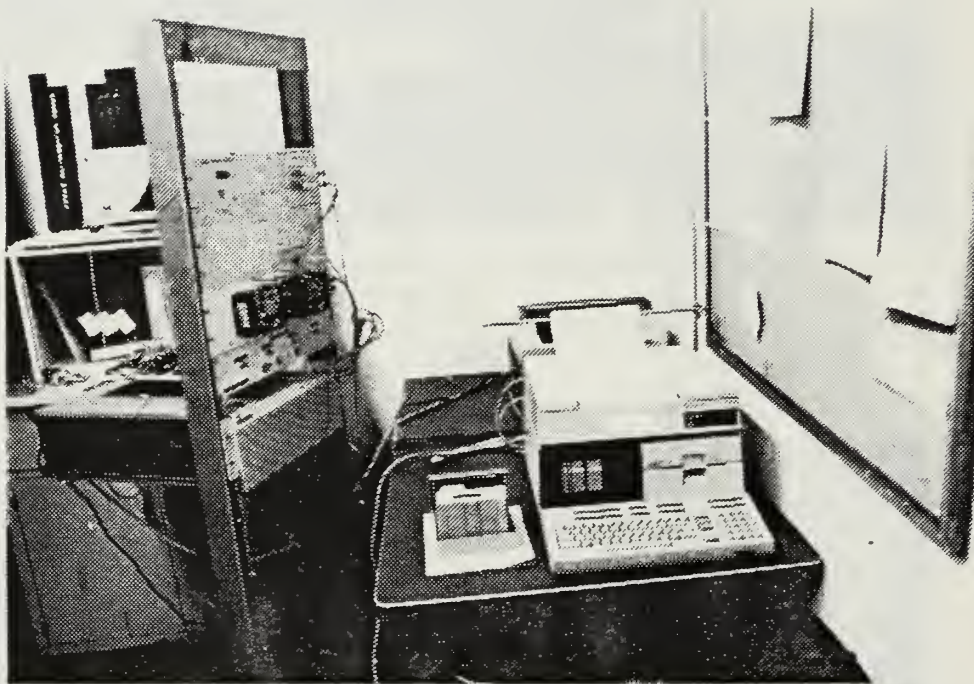


Figure 19. HP-9826 Microcomputer



### 1. Probe Angle Adjustment

As discussed in Section III.E, a potentiometer configured as a voltage divider provided probe angle feedback to the computer as shown in Figure 20. The direction of motor rotation was controlled by the computer through Type-MRR1CDL replays connected as shown in Figure 21. When the probe was at a desired position, a 5.0 VDC signal was applied to pins 6L and 6R which allowed both relays to assume the normally closed (NC) positions which opened the power circuit to the motor. When it was desired to rotate the motor clockwise, pin 6R was grounded which resulted in 5.0 VDC applied across the coil in the right-hand relay. This caused the relay to assume its normally open (NO) position resulting in a 1.5 VDC signal at terminal B of the motor causing it to rotate in the clockwise direction. The left-hand relay was activated in a similar manner for counterclockwise rotation. Refer to PROBE\_SUBS in Appendix B for probe positioning software.

### 2. 3-D Positioning Platform Movement

Positioning platform movement was controlled in a manner similar to the probe and was discussed in detail by Nickodem [Ref. 2]. Refer to MTR\_SUBS in Appendix B for associated HP-9826 software.

### 3. Temperature Data Collection

Three thermocouples were monitored in the data collection process. A Type-T thermocouple located in the inlet chamber measured the ambient fluid temperature in the flume,

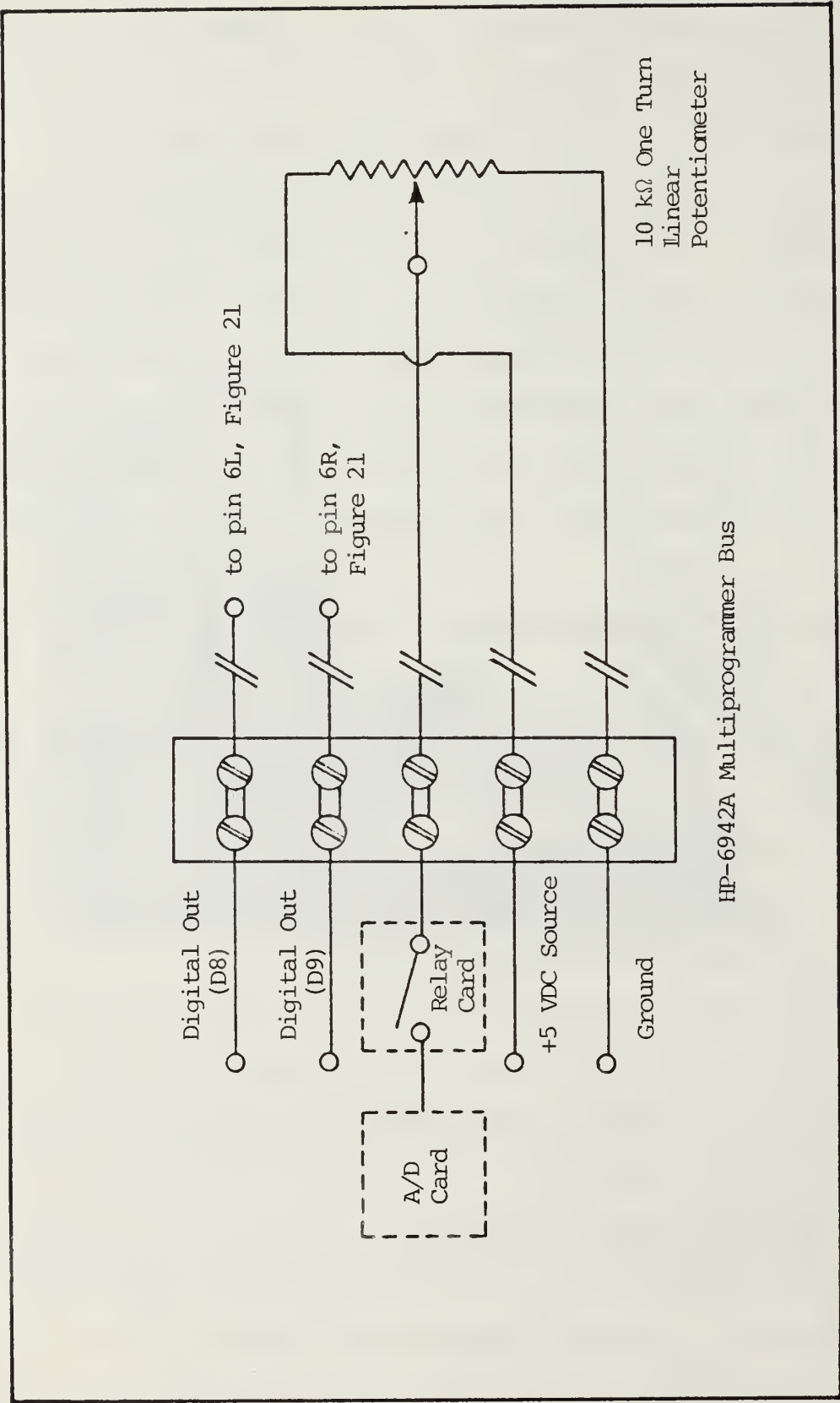


Figure 20. Computer Bus and Probe Voltage Divider Wiring Diagram

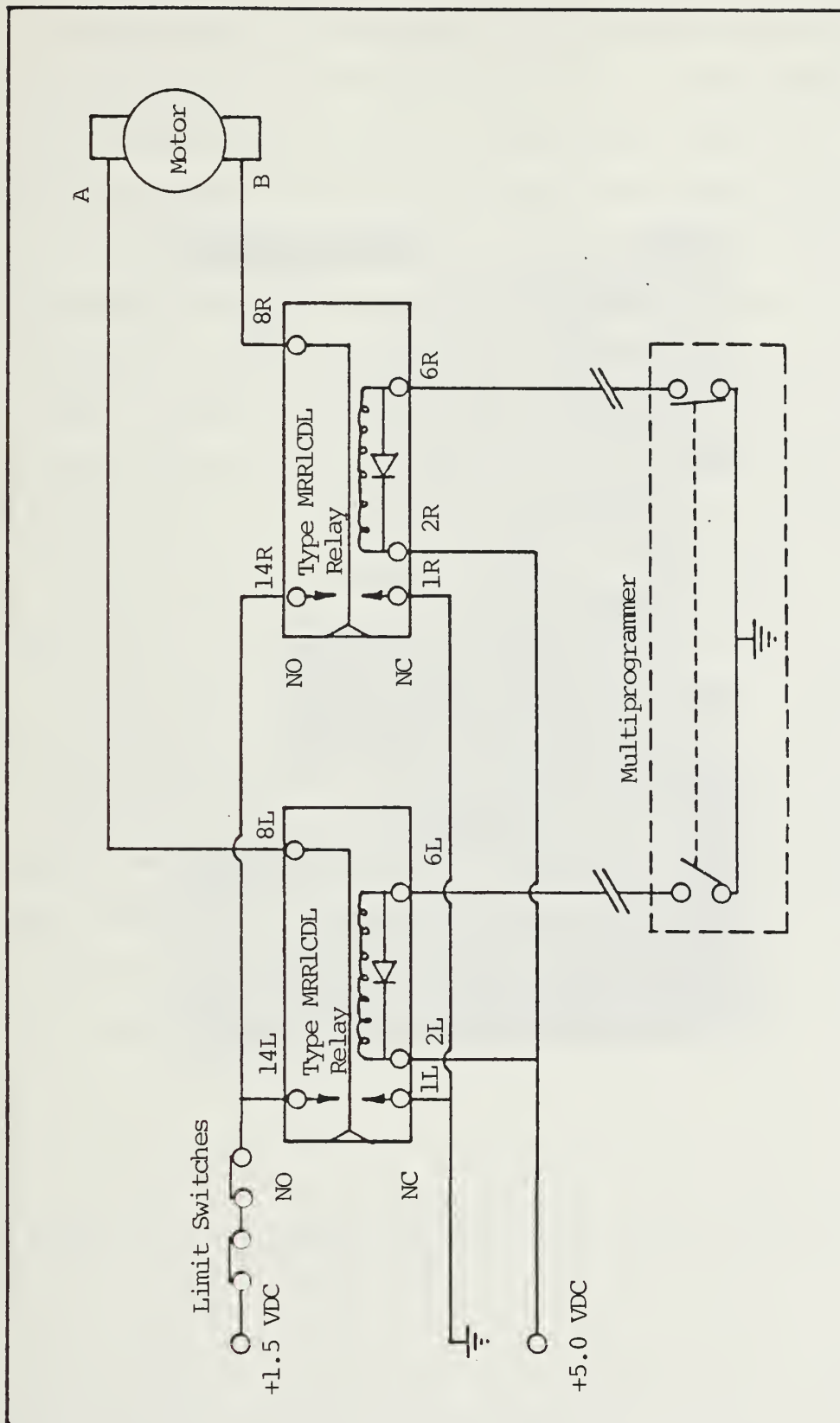


Figure 21. Probe Motor Wiring Diagram

a Type-T thermocouple located in the tubing between the heater and the nozzle measured nozzle temperature and a Type-E microthermocouple in the probe measured the temperature in the jet. The EMF's generated by these thermocouples were amplified by "Omega Omni-Amp IIB" millivolt amplifiers shown in Figure 22 prior to entering the multiprogrammer for analog-to-digital conversion and eventual transformation to temperature readings. Fourth-order least squares coefficients for this conversion were taken from Beckwith [Ref. 5]. Operation of the crossflow circulation pump created sufficient electrical interference to distort the thermocouple signals. This problem was corrected by applying a thin coating of silicon sealant to the Type-T thermocouple junctions and by connecting the crossflow circulation pump casing, the nozzle and the jet tubing in the vicinity of the nozzle thermocouple to a common ground. Because the jet tubing was plastic, it was necessary to manufacture a brass "T" connector as shown in Figure 23 which was grounded and located in close proximity to the thermocouple junction. Refer to T\_SUBS in Appendix B for associated software.

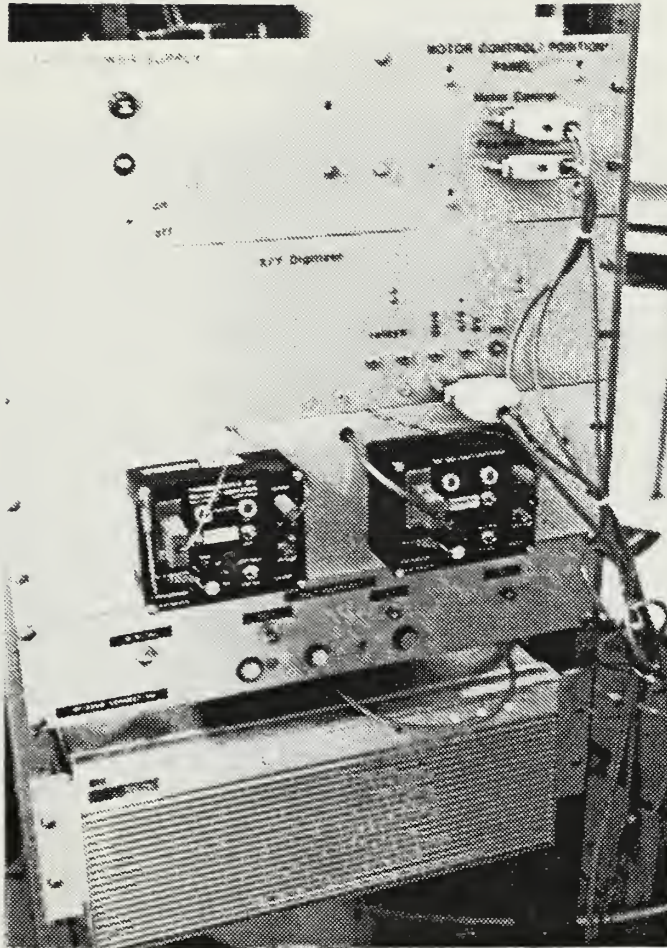


Figure 22. Thermocouple Amplifiers and HP-6942A Multiprogrammer



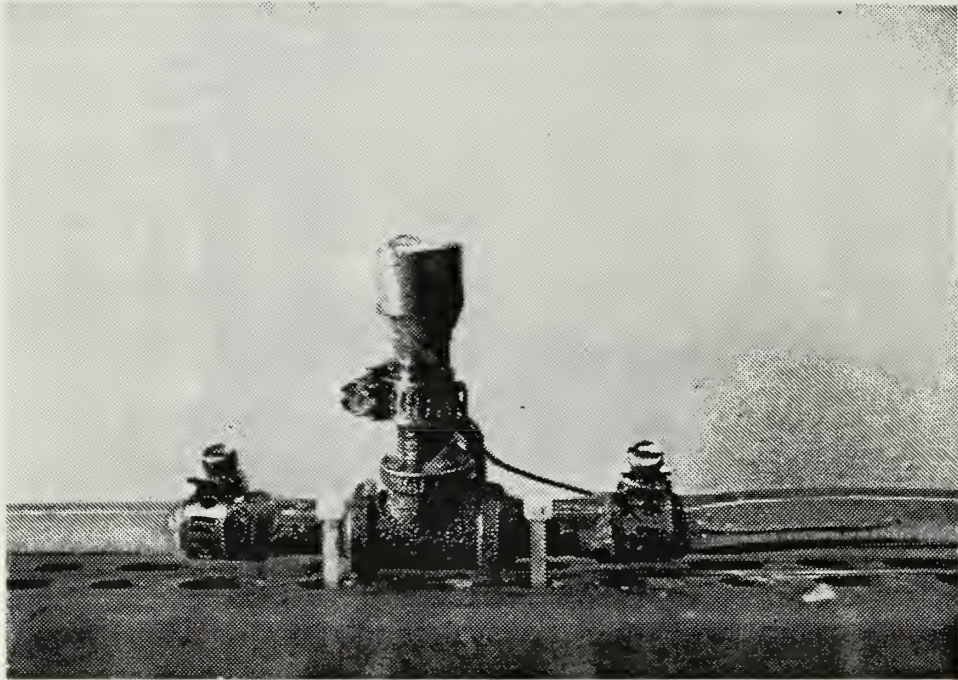


Figure 23. Nozzle Thermocouple Grounding Arrangement



## IV. EXPERIMENTAL PROCEDURES

### A. CALIBRATION

Before the data collection process could begin, the rotometer, the thermocouples, the probe and the positioning platform had to be calibrated. The detailed steps taken are discussed below.

#### 1. Rotometer

With a constant level maintained in the head tank and the jet tubing disconnected from the nozzle and elevated to the same height as the top of the nozzle, five 100 ml samples were drawn through the rotometer and timed to the nearest 0.01 second at each rotometer reading from 10% to 75% in 5% increments. Flowrates and standard deviations in ml/s are shown in Table 1.

#### 2. Thermocouples

Since nozzle and probe temperatures were to be normalized by the ambient temperature, the nozzle and probe thermocouples were calibrated relative to the ambient thermocouple by using the microcomputer program T\_CAL in Appendix B. The procedure followed is outlined in the initial comments of the program. Coefficients for first order curve fits were solved by the least squares method with the mainframe programs TCAL and TFIT found in Appendix C.

### 3. Probe

As the probe assembly was being developed, it was convenient to test its suitability with the probe calibration panel shown in Figure 24. Resistance changes across the potentiometer were recorded for varying degrees of deflection. Analysis of this information led to improved designs from the standpoint of reduced hysteresis and repeatability. The microcomputer program PROBE\_CAL in Appendix B was developed to enable calibration of the final design after it was installed in the system as shown in Figures 25 and 26. The calibration procedure is outlined in the preliminary comments of the program.

### 4. 3-D Positioning Platform

The positioning platform was calibrated in a manner that placed the tip of the probe at desired locations within the flume relative to the tip of the nozzle. Referring to the coordinate system illustrated in Figure 2, the center of the nozzle was defined as (0,0,0) in xyz-coordinates. The following relationships apply to the probe geometry shown in Figure 27:

$$X(\text{real}) = X_o - R_a \cos \alpha \tan(\pi/4 - \alpha/2)$$

$$Y(\text{real}) = Y_o + r_p (1 - \cos \gamma) + R_a \cos \alpha$$

$$Z(\text{real}) = Z_o - r_p \sin \gamma$$

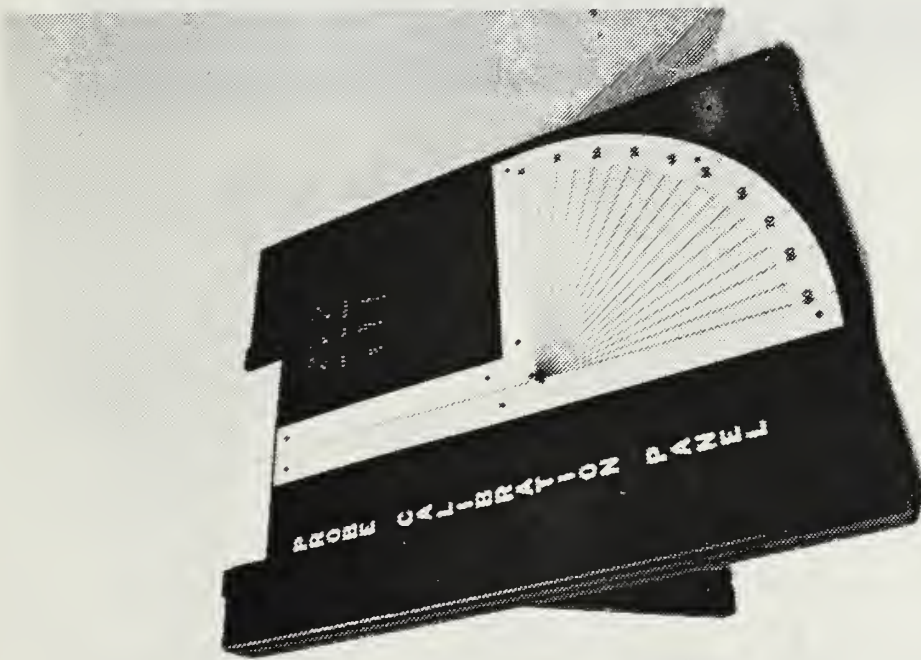


Figure 24. Probe Design Test Panel

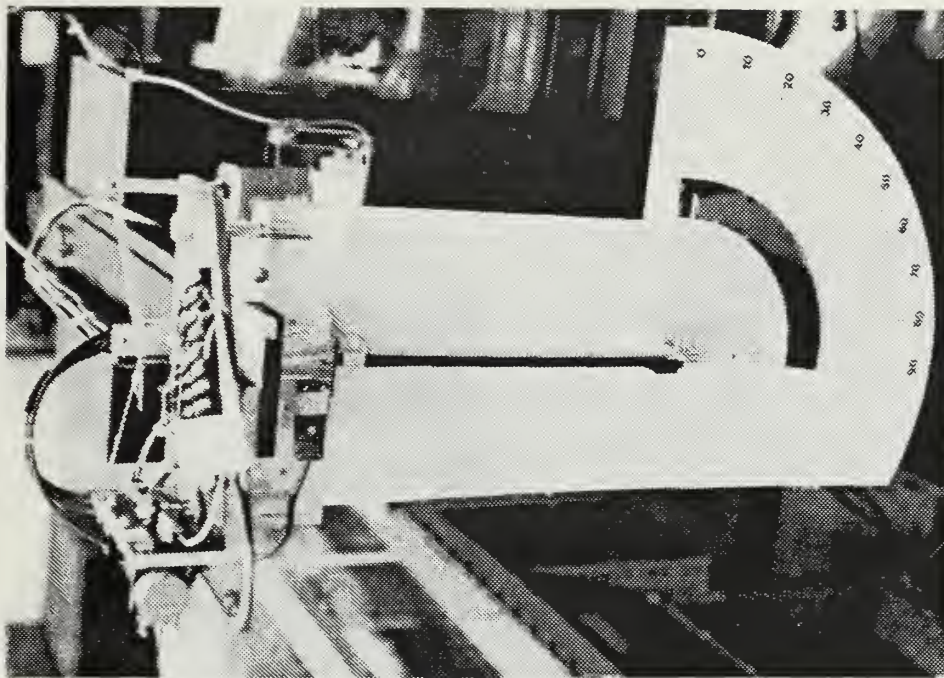


Figure 25. Probe Calibration Panel



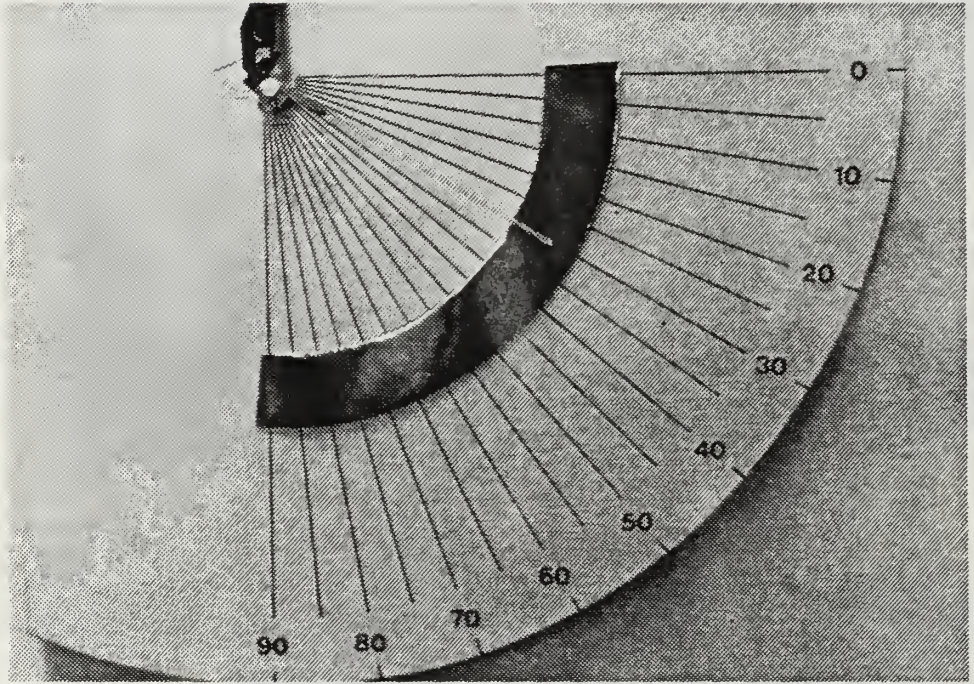


Figure 26. Probe Calibration Panel



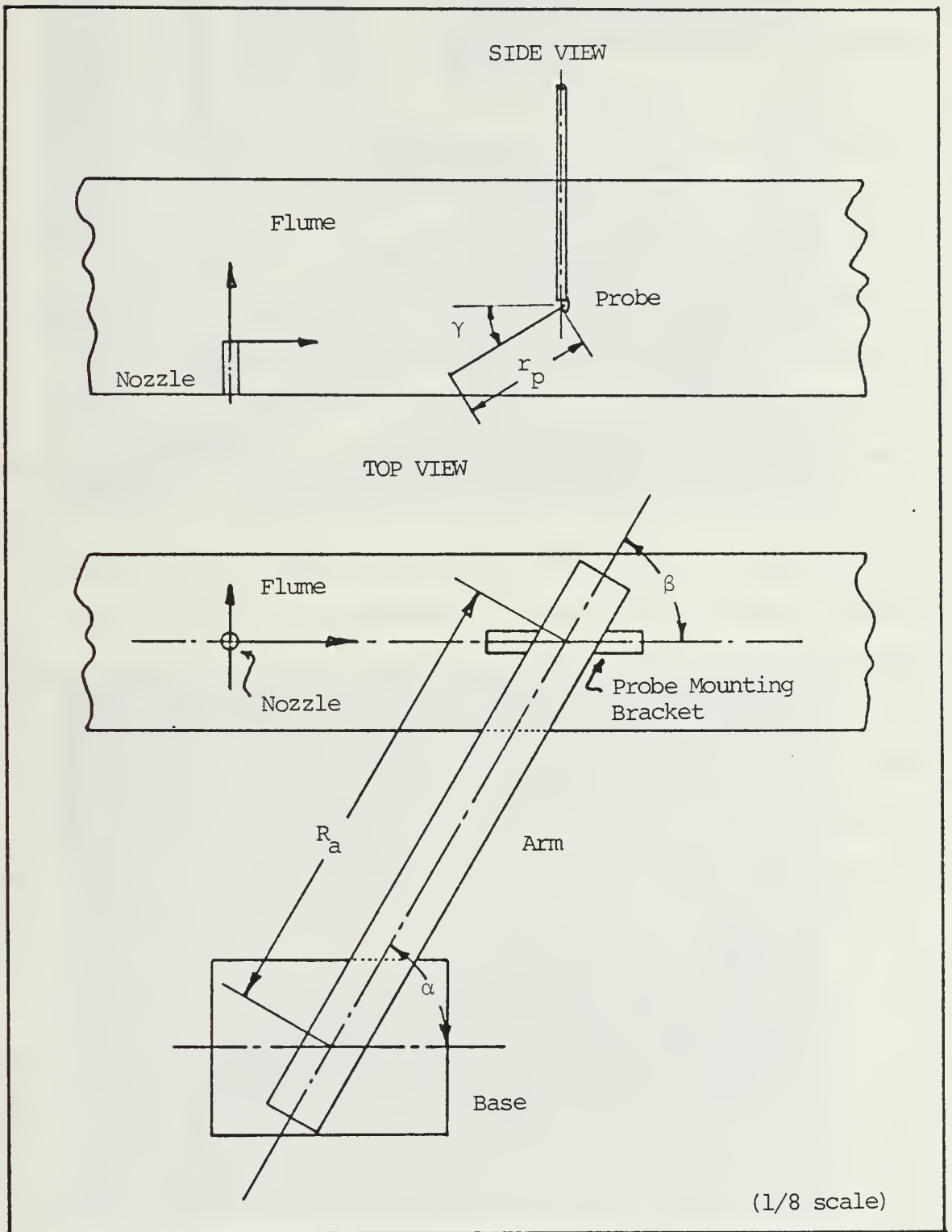


Figure 27. Probe Positioning Geometry

$(X_o, Y_o, Z_o)$  was the position of the milling machine bed when the tip of the probe was at position  $(0,0,0)$  with  $\gamma = 0$  and  $\alpha = \beta = 90$  degrees. For calibration, the probe and probe arm were configured with these settings as shown in Figure 28. With measured values of  $r_p$  and  $R_a$  entered into the microcomputer program MAIN\_T, the calibration was accomplished by the program MOTOR\_CAL. The step-by-step procedure followed was outlined in the subprogram "SUB Calibrate." As illustrated in Figures 3, 27 and 28, the length of  $R_a$  could be modified to compensate for adjustments of  $\alpha$  and  $\beta$  to positions other than 90 degrees. Decreasing  $\alpha$  increased the distance along the Y-axis in which the probe could be positioned. Increments of  $\alpha$  and  $\beta$  were scribed on the top of the base and at the tip of the probe arm in Figure 28 to accommodate this change, if desired. The program MAIN\_T queried the user for the value of  $\alpha$  and assumed  $\alpha = \beta$ . The calibration software also established position limits to prevent driving the probe into the sides of the flume.

## B. PRELIMINARIES

Crossflow velocity was determined by injecting blue food coloring into the flow and timing its travel through a 1.0 m interval. The average of several trials indicated the velocity was .130 m/s (.427 ft/sec) with the flume outlet valve closed two turns from its fully open position.

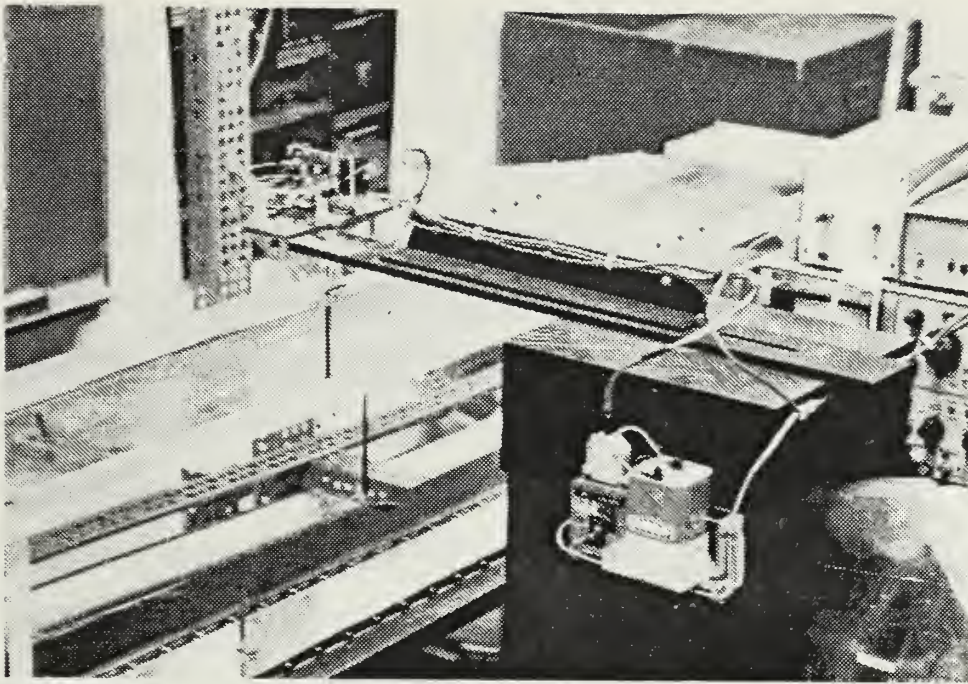


Figure 28. Probe Arm Positioning for Motor Calibration

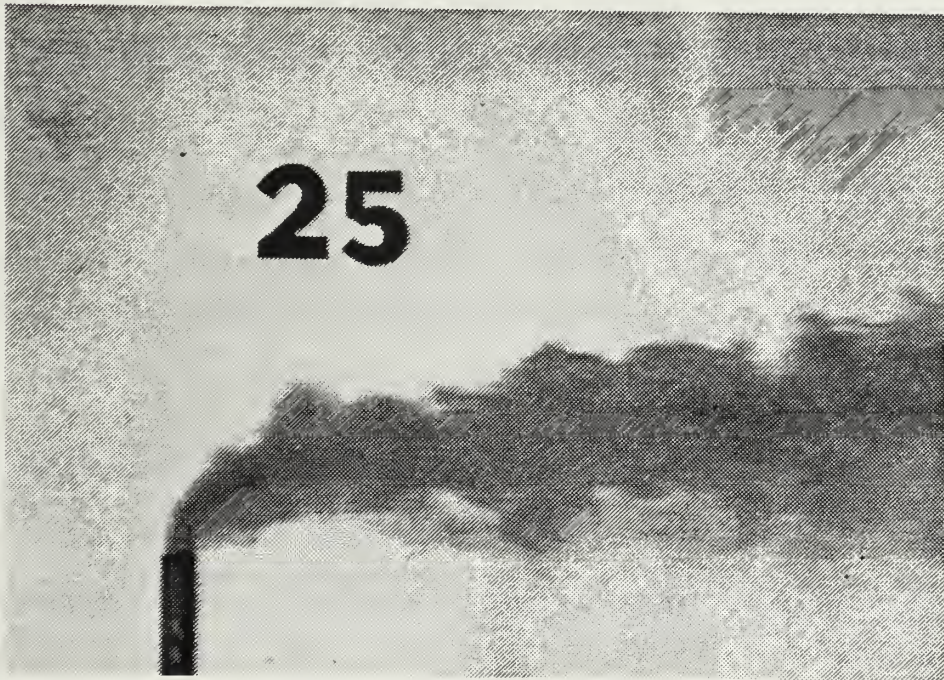


Figure 29. Typical Buoyant Jet as Observed with Dye Injected



Photographs of jet profiles as shown in Figure 29 were taken to determine jet trajectory and halfwidths along the streamwise axis. This was done by injecting blue food coloring into the jet flow as discussed in Section III.C. The specific gravity of the food coloring was found to be considerably less than that of water. To eliminate the added buoyant effect this would have had on the jet, a small quantity of alcohol was mixed with the food coloring as suggested by Merzkirch [Ref. 6]. The amount of alcohol added was determined by trial and error. As small quantities were added and mixed, samples were gently placed on the surface of a beaker of water. Pure food coloring laid on the surface and very slowly mixed with the water. As alcohol was added, this buoyant effect grew progressively less and the mixture would settle into the water. The mixture was considered satisfactory when it no longer laid on the surface, but settled to some equilibrium position in the beaker.

Slide photographs of the jets were projected onto large sheets of 3.175 mm (.125 in) grid graph paper and digitized along approximate streamwise axes and half-width trajectories. A scaling factor was determined by equating the projected width of the nozzle to its known outer diameter of 7.9375 mm (.3125 in). The above data was fit to the Michaelis-Menter Equation [Ref. 7] shown below by the least squares method with the mainframe program JETCURV in Appendix C:

$$z = \frac{ay}{b + y}$$



Correlation coefficients close to 1 were consistently obtained. To determine positions within the jet at which to make temperature measurements, five evenly spaced positions per jet flow rate were selected along the streamwise axis in the zone of established flow. Data planes slightly larger than the jet width were centered at these points and oriented perpendicular to the streamwise axis. One hundred data points were selected in a symmetric square matrix with points most densely populated near the center. The planes were identified alphabetically and in consecutive order from "A" to "F", where "A" represented the plane nearest the nozzle. The positions were entered into the microcomputer and stored by plane on a floppy disk by the program LOAD\_XYZ in Appendix B. Accompanying each data point was a probe deflection angle used to orient the probe parallel to the path of the jet to minimize interference. This angle was determined by evaluating the first derivatives of the equations developed for the streamwise axis and the half-widths and performing an interpolation based upon the data points' position relative to the two curves.

### C. DATA ACQUISITION

The flow systems were placed into operation and the ambient and nozzle temperatures were monitored with the program T\_SUBS to evaluate system stability and readiness for data acquisition. The system usually took approximately two hours to come into equilibrium. This could be monitored

by watching the jet nozzle temperature. When conditions were stable, data consisting of two hundred probe, ten ambient and ten nozzle temperature samples per position was collected, one plane at a time, by the program MAIN\_T. The following information was stored on a floppy disk for each data point: x, y, and z coordinates; mean probe, nozzle and ambient temperatures and the standard deviation of the probe measurements. The data was transferred to the mainframe computer by using a modem, the microcomputer program SEND\_DATA and the mainframe program GRAB.

#### D. DATA REDUCTION

The raw data was organized into a more usable format by the mainframe program TDATA which also converted the XYZ coordinates into the XSW system shown in Figure 2. The resulting data was selectively sent to the program CONTOUR4 which applied calibration coefficients to the temperature data and normalized it in the following manner:

$$T = \frac{T_p - T_a}{T_n - T_a}$$

where  $T_p$  was the jet temperature as measured by the probe,  $T_a$  was the ambient fluid temperature and  $T_n$  was the temperature of the jet within the nozzle.

Contour plots of this information, generated by the CONTOUR option of the graphics package DISPLA [Ref. 8], are presented in Figures 30 through 35.

TEMPERATURE CONTOURS IN A BUOYANT JET  
WITH A CROSSFLOWING AMBIENT  
(25% FLOW RATE)  
(PLANE A)

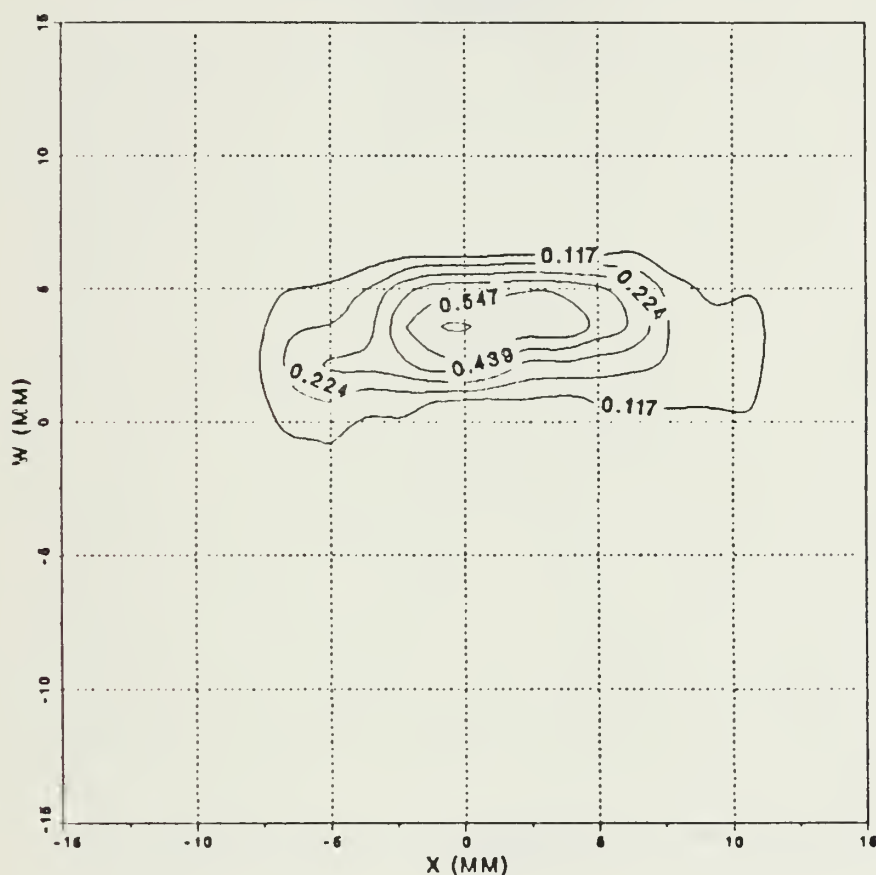


Figure 30. Plane A Temperature Contour Plot  
(large scale)

# TEMPERATURE CONTOURS IN A BUOYANT JET WITH A CROSSFLOWING AMBIENT (25% FLOW RATE) (PLANE A)

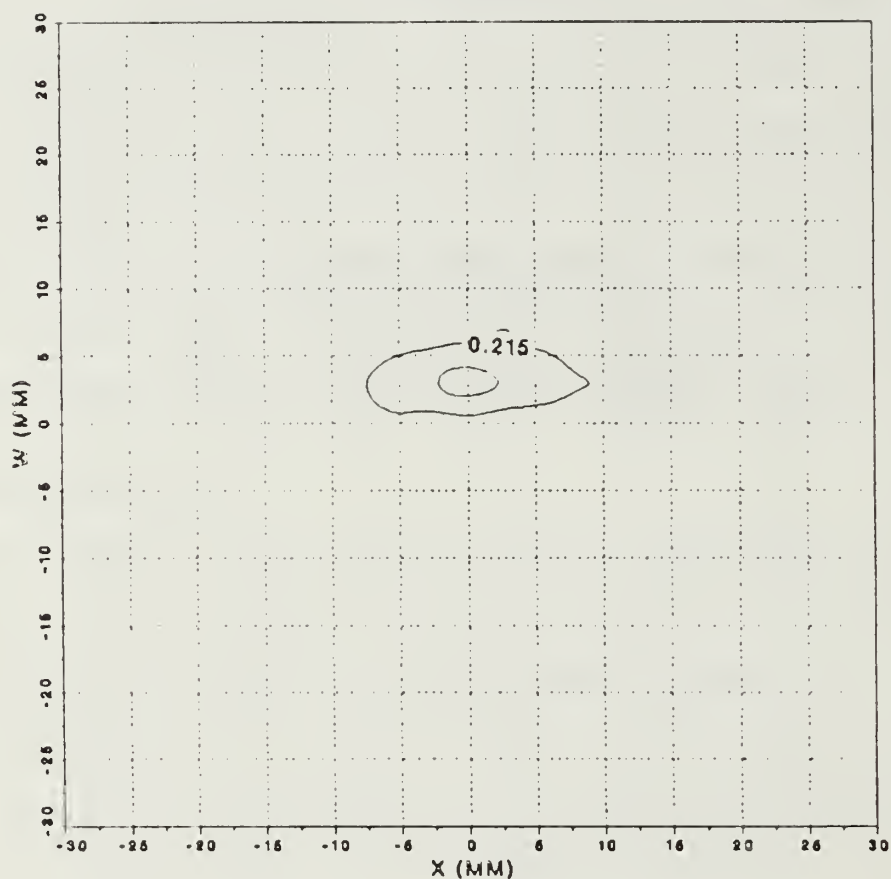


Figure 31. Plane A Temperature Contour Plot  
(small scale)



# TEMPERATURE CONTOURS IN A BUOYANT JET WITH A CROSSLFLOWING AMBIENT (25% FLOW RATE) (PLANE B)

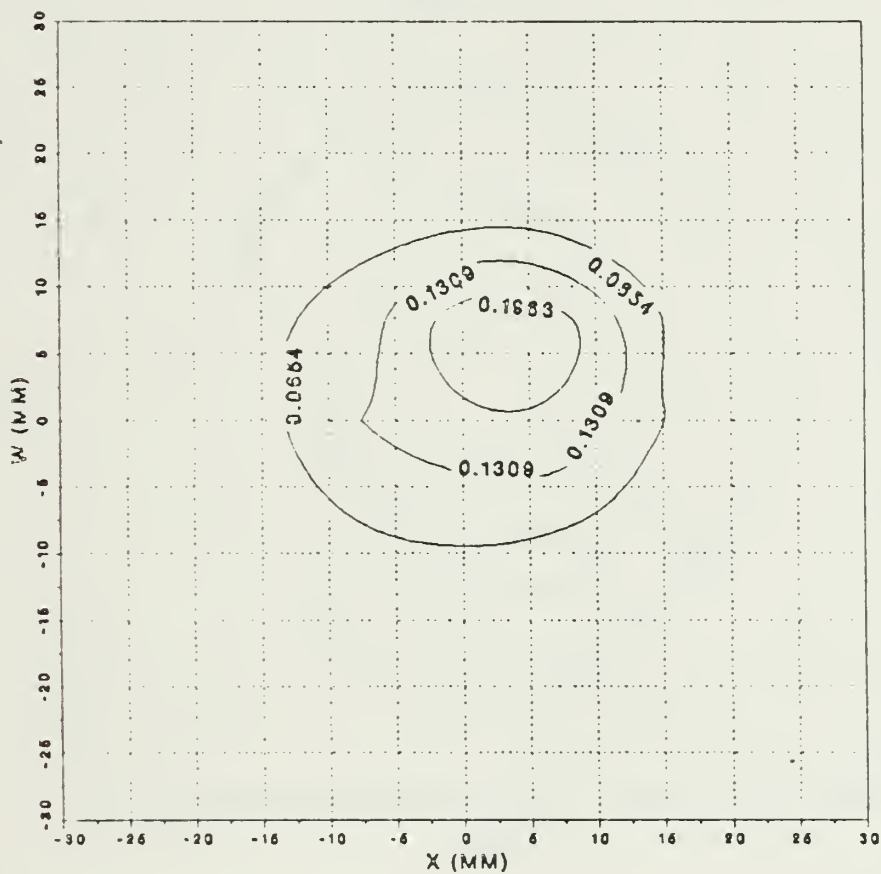


Figure 32. Plane B Temperature Contour Plot

TEMPERATURE CONTOURS IN A BUOYANT JET  
WITH A CROSSFLOWING AMBIENT  
(25% FLOW RATE)  
(PLANE C)

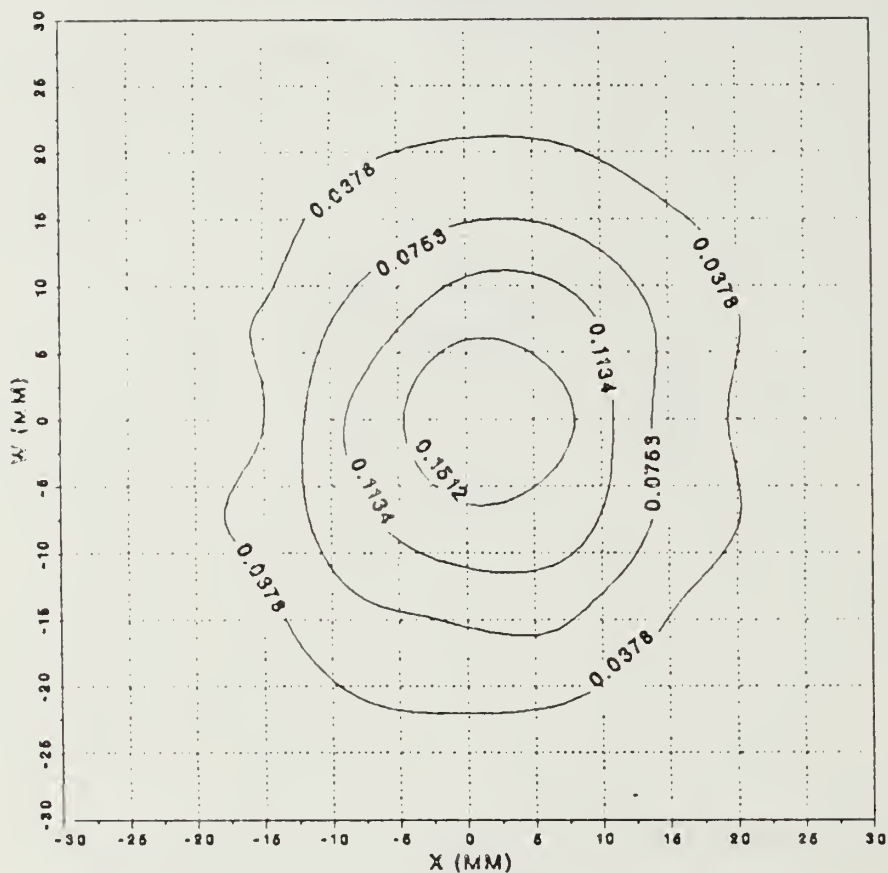


Figure 33. Plane C Temperature Contour Plot

# TEMPERATURE CONTOURS IN A BUOYANT JET WITH A CROSSFLOWING AMBIENT (25% FLOW RATE) (PLANE D)

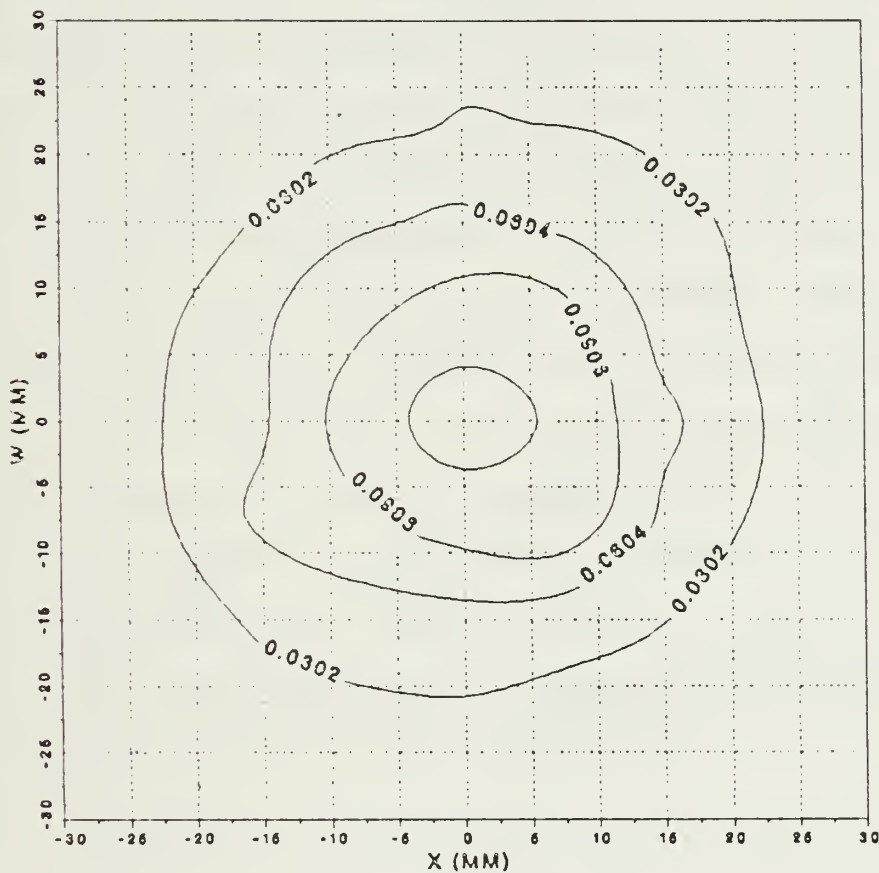


Figure 34. Plane D Temperature Contour Plot

# TEMPERATURE CONTOURS IN A BUOYANT JET WITH A CROSSFLOWING AMBIENT (25% FLOW RATE) (PLANE E)

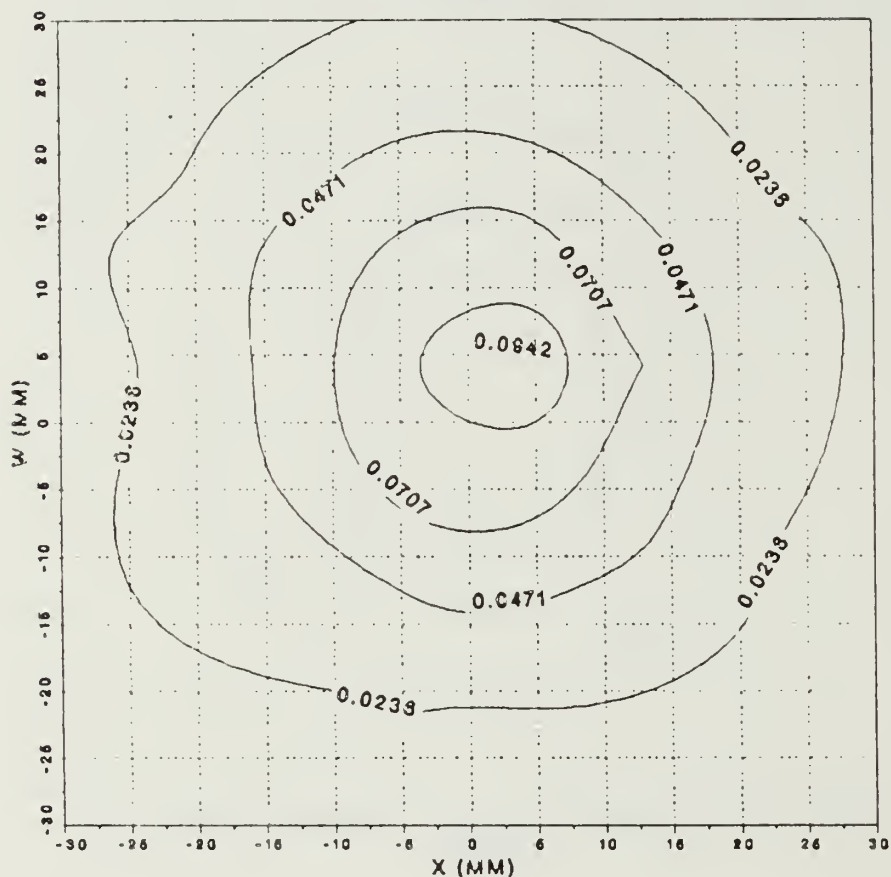


Figure 35. Plane E Temperature Contour Plot



## E. RESULTS

The contour plots found in Figures 30 through 35 support the conjectures in Section II.C concerning the effects of the crossflow. Figure 30, a plot of plane A centered on the streamwise axis 46 degrees from horizontal and 7.327 mm (.288 in) downstream of the nozzle shows significant distortion. Figures 31 through 35 show planes A through E sequentially plotted on the same scale in order to observe overall jet behavior. Plane E was located 87.313 mm (3.438 in) downstream of the nozzle and 86 degrees from horizontal. It can be seen that as the jet traveled further downstream, the distorting effect grew progressively less, as expected.

The rate of heat transfer from the jet to the ambient was calculated for each plane utilizing the temperature distribution matrix generated in the program CONTOUR4 in Appendix C and the following relationship:

$$\dot{Q} = \sum_{i=1}^m \sum_{j=1}^n \rho c_p A_{ij} U_{ij} T_{ij}$$

where  $\rho$  was the relative density of the jet,  $A_{ij}$  was the area of each matrix segment,  $U_{ij}$  was the velocity in each segment,  $c_p$  was the specific heat of the jet and  $T_{ij}$  was the temperature in each segment. Velocity was measured along the streamwise axis by a laser Doppler velocimeter (LDV). It appeared to be nearly constant in the region of the jet observed. The mean and standard deviation was 44.875 mm/s

and 1.8 mm/s respectively. By assuming the Gaussian profile shown in Section II.B, velocity was determined at radii corresponding to each segment in the matrix mentioned above. The rates of heat transfer are shown in Table 2.

## V. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to develop a computer-aided data acquisition system and construct a microthermocouple probe to be used by follow-on students to study temperature distributions in turbulent buoyant jets. Sample data was taken to verify system operability. Based on results, the system performed in a satisfactory manner and will be an invaluable tool for subsequent studies of buoyant jets in a crossflowing ambient.

Data point positions were hand calculated and loaded into the microcomputer with the program LOAD\_XYZ. This was an extremely time consuming task and distracted the user from defining more than 100 data points per plane. The system can be greatly improved with the addition of microcomputer software that would automatically determine and load data point positions. Data point population could then be increased with ease which should result in smoother contour plots and more accurate heat transfer calculations.

It was necessary to continuously add fresh water to the crossflow system as an equal amount was drained from it in order to maintain the crossflowing ambient at a constant temperature. This was because the cooling coil located within the flow settling chamber was inadequate to compensate for the heat added to the system by the jet and the

crossflow circulation pump by itself. Although it was possible to maintain the ambient constant within 1.4 C by this method, in the interest of conserving water, it is recommended that either a larger capacity chilled water bath or a cooling system that circulates a refrigerant rather than water be appropriated for this purpose.



APPENDIX A  
UNCERTAINTY ANALYSIS

Experimental uncertainty was analyzed in accordance with the guidelines set forth by Holman [Ref. 9]. Uncertainties in the primary measurements, based upon manufacturer specifications and/or the number of significant digits which could be read, follow:

1. Time (rotometer calibration):	.01 s
2. Volume (rotometer calibration):	1.0 ml
3. Rotometer reading:	1.0 percent
4. 3-D positioning platform resolution:	.1524 mm
5. Probe deflection angle resolution:	.5 degrees
6. Thermocouple resolution:	.0099 °C
7. Thermocouple time constant:	.004 s
8. Time (crossflow velocity):	.01 s
9. Length (crossflow velocity):	.05 m

Based on the above, the uncertainty of the flow rate of the jet was estimated to be 1.0 ml/s. Maximum uncertainty in the position of the probe's tip due to the uncertainty in deflection angle was determined to be .983 mm (.0387 in). Combined with the resolution of the positioning platform, the tip of the probe was positioned with an uncertainty of 1.135 mm (.0447 in) in each plane, or with an overall uncertainty of 1.605 mm (.063 in) in three-dimensional

space. Temperature was measured at the approximate rate of 100 samples per second, well within the constraints of the thermocouple time constant. Uncertainty in the temperature measurements were governed by the resolution of the analog-to-digital converter which was .0099 °C. Uncertainty in the crossflow velocity was .00625 m/s (.0205 ft/sec).

## APPENDIX B

### MICROCOMPUTER PROGRAMS

#### 1. MAIN\_T

```

10  ! MAIN_T
20  !
30  !   This program coordinates the entire
40  !   data-taking evolution for measuring
50  !   temperature distributions in buoyant
60  !   jets.
70  !
80  !
90  !   1. Load all subprograms
100 !   2. Input desired positions from a
110 !   disk file of the form : "RUNEX"
120 !   (value "XX" is the run number)
130 !   3. Move the 3-D positioning
140 !   platform to each position
150 !   4. Align the thermocouple probe with
160 !   the jet streamwise axis
170 !   5. Obtain 200 temperatures at each
180 !   position and compute the mean and
190 !   standard deviation (sd)
200 !   6. Write to disk:
210 !       a. T(C)
220 !       b. sd
230 !       c. x,y,z in (mm)
240 !           nozzle centerline is (0,0,0)
250 !
260 !   Probe and arm dimensions in inches:
270 !       a. Shortest arm length = 20.0
280 !       b. Longest arm length  = 24.0
290 !
300 Length_probe=4.4375
310 Length_arm=20.0
320 !
330 OPTION BASE 1
340 DIM Coef(12),X(500),Y(500),Z(500),Probe_angle(500)
350 LOADSUB ALL FROM "T_SUBS"
360 LOADSUB ALL FROM "MTR_SUBS"
370 LOADSUB ALL FROM "PROBE_SUBS"
380 CALL Retrieve_coef(Coef(*),"motor_coef")
390 !
400 !   2. Input desired positions from disk
410 !
420 I=1
430 INPUT "Angle of arm relative to +Y-axis?",Angle_arm
440 INPUT "Filename for positioning data?",Filename$
450 ASSIGN @File4 TO Filename$
460 Go_on: !
470 ENTER @File4;X(I),Y(I),Z(I)
480 !
490 IF X(I)<>-100 THEN
500 IF X(I)=-999 THEN
510 Probe_angle(I)=Y(I)
520 P_angle=Y(I)
530 ELSE
540 Probe_angle(I)=P_angle
550 I=I+1
560 END IF
570 !
580 GOTO Go_on
590 END IF
600 !

```

```

610      !
620      GOTO Go_on
630      END IF
640      !
650      ASSIGN @File4 TO *
660      Nitems=I-1
670      !
680      !3. Begin loop to take data at each point
690      !
700      INPUT "NAME OF FILE WHERE DATA IS TO BE STORED?",Filename1$
710      Records=(Nitems*8*7/256)+2
720      CREATE BDAT Filename1$,Records
730      ASSIGN @File1 TO Filename1$
740      !
750      !
760      !
770      FOR I_position=1 TO Nitems
780      !
790      !a. Move milling machine and move the
800      !      thermocouple probe.
810      !
820      I=I_position
830      CALL Move_ldv_to(X(I),Y(I),Z(I),Lenght_arm,Length_probe,Angle_arm,
e_angle(I),Coef(*))
840      !
850      !
860      !b. Obtain mean temperature and sd
870      !
880      CALL T_couple(T,"PROBE","C",200,St_dev)
890      !
900      !c. Measure ambient and jet temps
910      !
920      CALL T_couple(T_ambient,"AMBIENT","C",10,Sd)
930      CALL T_couple(T_nozzle,"NOZZLE","C",10,Sd)
940      !
950      !d. Write all information to disk
960      !
970      OUTPUT @File1;X(I),Y(I),Z(I)
980      OUTPUT @File1;T,T_ambient,T_nozzle
990      OUTPUT @File1;St_dev
1000     NEXT I_position
1010     !
1020     !4. Close files
1030     !
1040     OUTPUT @File1;-100
1050     ASSIGN @File1 TO *
1060     !
1070     !5. Terminate program
1080     !
1090     PRINT "All done!"
1100     BEEP
1110     BEEP
1120 END

```



## 2. PROBE\_SUBS

```

10      ! PROBE_SUBS
20      !
30      ! This program moves the temperature probe
40      ! to desired angles of deflection.
50      !
60      ! NOTE: Calibration coefficients are
70      ! entered in SUB Read_angle.
80      ! beginning at line 290.
90      !
100     CALL Read_angle(Angle)
110     PRINT "The probe is presently at";Angle;" degrees from horizontal."
120     INPUT "What is your desired angle for the probe?",Desired_angle
130     CALL Probe_move(Desired_angle)
140     GOTO 120
150     END
160     !
170     !
180     !
190     SUB Read_angle(Actual_angle)
200     !This program reads the present angle
210     !of the probe and returns it.
220     ! 0 degrees = horizontal
230     !90 degrees = vertical, downward
240     !
250     !A0, A1 and A2 = coefficients for a
260     !second order curve fit of mV vs angle
270     !of deflection data.
280     !
290     !Coefficients for 8 June data follow:
300     !
310     A0=-23.8657824056449
320     A1=3.09995506283164E-2
330     A2=-1.22922305456149E-6
340     ! ! FORMAT A/D CARD
350     OUTPUT 723;"CC,1T" !Clear Relay Card
360     OUTPUT 723;"CC,3T" !Clear A/D Card
370     OUTPUT 723;"CC,7T" !Clear Digital Card
380     OUTPUT 723;"SF,3,3,3,1.25,12T"
390     OUTPUT 723;"OB,1,10,1T" ! CLOSE RELAY
400     OUTPUT 723;"IP,3T" ! START A/D
410     ENTER 72301;V
420     Actual_angle=A0+A1*V+A2*V*V
430     SUBEND
440     !
450     !
460     !
470     SUB Probe_move(Desired_angle)
480     !This subprogram moves the probe to the
490     !desired angle
500     !
510     ! 0. Check to see if the angle is in
520     ! an acceptable range.
530     !
540     OUTPUT 723;"OP,1,0T" !Clear Relays
550     CALL Clear_screen
560     !
570     IF Desired_angle>90 THEN
580         BEEP 3400.1
590         BEEP 1700.1

```

```

600         BEEP 3400,1
610         PRINT "Desired angle exceeds 90 degrees!!!"
620         SUBEXIT
630     END IF
640     !
650     IF Desired_angle<0 THEN
660         BEEP 3400,1
670         BEEP 3800,1
680         BEEP 3600,1
690         PRINT "Desired angle is negative!!!"
700         SUBEXIT
710     END IF
720     !
730     ! 1.a. Clear the digital output card.
740     !     b. Format the A/D card.
750     !     c. Close the relay that corrects
760     !         the probe potentiometer to the
770     !         A/D converter.
780     !
790     OUTPUT 723;"OP,7,0T"
800     OUTPUT 723;"SF,3,3,3,1.25,3T"
810     OUTPUT 723;"CC,1T"
820     OUTPUT 723;"OB,1,10,1T"
830     !
840     ! 2. Define the acceptable tolerance
850     !     in the angle (degrees).
860     !
870     Tolerance=.5
880     !
890     ! 3. Control loop.
900     !
910 Repeat: CALL Read_angle(Actual_angle)
920         PRINT "ANGLE =";
930         PRINT USING "DDD.DD";Actual_angle
940         BEEP Actual_angle*100,.05
950         Angle_error=(Desired_angle-Actual_angle)
960         !
970         IF ABS(Angle_error)>Tolerance THEN
980             !
990             IF Angle_error>=0 THEN
1000                Direction$="Down"
1010            ELSE
1020                Direction$="Up"
1030            END IF
1040            !
1050            CALL Motor_go(Direction$)
1060            !
1070            GOTO Repeat
1080        END IF
1090 OUTPUT 723;"OP,7,0T"
1100 OUTPUT 723;"CC,1T" !Clear relay card.
1110 SUBEND
1120 !
1130 !
1140 !
1150 SUB Motor_go(Direction$)
1160     IF Direction$="Up" THEN
1170         Lbit=8
1180     END IF
1190     !

```

```

1200     IF Direction$="Down" THEN
1210         Lbit=7
1220     END IF
1230     !
1240     OUTPUT 723;"OP,7";2^Lbit;"T"
1250 SUBEND
1260 !
1270 !
1280 !
1290 SUB Clear_screen
1300 ! Clear the CRT.
1310 !
1320     OUTPUT 2 USING "#,B";255,75
1330     GCLEAR
1340 SUBEND

```

### 3. MTR\_SUBS

```
10      ! MTR_SUBS
20      !
30      ! The following series of subroutines
40      ! are utilized to calibrate the positioning
60      ! platform and ultimately to move the probe
70      ! tip to desired positions within the jet.
80      !
90      SUB Draw_flume
100     !
110     ! Draw the Buoyant Jet Flume on the CRT.
120     !
130     GCLEAR
140     GRAPHICS ON
150     WINDOW 0,48,0,38
160     LINE TYPE 1
170     MOVE 6,6
180     ! Draw the top view
190     IDRAW 36,0
200     IDRAW 0,10
210     IDRAW -36,0
220     IDRAW 0,-10
230     !
240     IMOVE 6,0
250     IDRAW 0,10
260     IMOVE 24,0
270     IDRAW 0,-10
280     ! label "Top".
290     MOVE 0,10
300     CSIZE 5
310     LABEL "Top"
320     ! Draw the side view.
330     MOVE 6,22
340     IDRAW 36,0
350     IDRAW 0,13
360     IDRAW -36,0
370     IDRAW 0,-13
380     IMOVE 6,0
390     IDRAW 0,13
400     IMOVE 24,0
410     IDRAW 0,-13
420     ! label "Side"
430     CSIZE 5
440     MOVE 0,29
450     LABEL "Side"
460     !
470     ! Label the picture.
480     !
490     MOVE 11,35
500     CSIZE 7
510     LABEL "BUOYANT JET FLUME"
520     !
530     ! Put on the nozzle.
540     !
550     MOVE 14,22
560     IDRAW 0,2
570     IDRAW 25,0
580     IDRAW 0,-2
590     !
600     IMOVE 0,-2
610     CSIZE 3
```



```

620 LABEL "nozzle"
630 !
640 MOVE 14.11
650 CSIZE 3
660 LABEL "o"
670 !
680 ! Indicate the direction of flow.
690 !
700 MOVE 8,11
710 IDRAW 2,0
720 IDRAW -.5,-.5
730 IDRAW .5,.5
740 IDRAW -.5,.5
750 !
760 MOVE 8,27
770 IDRAW 2,0
780 IDRAW -.5,-.5
790 IDRAW .5,.5
800 IDRAW -.5,.5
810 !
820 SUBEND
830 !
840 !
850 !
860 !
870 !
880 !
890 SUB Calibrate(Filename$)
900 !
910 OPTION BASE 1
920 DIM Coef(12)
930 !
940 ! Calibrate the positioners on the
950 ! milling machine movement.
960 ! Onto disk, write out the calibration
970 ! coefficients and the hard boundaries
980 ! that must be observed!
990 ! This file will be called "Motor_coef".
1000 !
1010 ! A. Position the probe volume at the
1020 ! wall of the tip of the nozzle. This
1030 ! position is (0,0,0). All readings
1040 ! will be in inches. Read all three
1050 ! potentiometers. Ask the user for the
1060 ! nozzle outer diameter and compute the
1070 ! zero position. Ask the user for the
1080 ! milling machine readings.
1090 !
1100 ! B. Next, move the bed to some new posi-
1110 ! tion using the override switches.
1120 ! Take readings from the pots and ask
1130 ! for the milling machine readings.
1140 ! Compute the calibration coefficients.
1150 !
1160 ! C. Move the bed to each of the extremes
1170 ! in the X, Y, and Z directions using
1180 ! the override switches and have the
1190 ! user tell the computer when each of
1200 ! these boundaries are hit. Enter each
1210 ! of these onto the disk file.

```

```

1220 !
1230 ! D. Disk file "Motor_coef":
1240 !
1250 !     1. x_zero, x_slope
1260 !     2. y_zero, y_slope
1270 !     3. z_zero, z_slope
1280 !     4. x_min, x_max
1290 !     5. y_min, y_max
1300 !     6. z_min, z_max
1310 !
1320 BEEP
1330     PRINTER IS 1
1340     GCLEAR
1350     OUTPUT 2 USING "#,B";255,75
1360 !
1370 PRINT "I. POTENTIOMETER CALIBRATION:      "
1380 PRINT "                                     "
1390 PRINT "     NOTE: 1. Probe must be horizontal"
1400 PRINT "           2. Arm must be parallel to "
1410 PRINT "               the bed axis           "
1420 PRINT "           3. ALPHA = BETA             "
1430 PRINT "                                     "
1440 PRINT "     A. Using the override switches,  "
1450 PRINT "         position the probe volume at "
1460 PRINT "         the outer wall of the tip of "
1470 PRINT "         the nozzle.                   "
1480 PRINT "                                     "
1490 PRINT "     B. I will need the nozzle O.D. and"
1500 PRINT "         the milling machine position. "
1510 PRINT "                                     "
1520 PRINT "{ Hit <cont>}"
1530 PAUSE
1540 BEEP 1500,.1
1550 INPUT "1. Nozzle O.D. (inches)?",Nozzle_od
1560 BEEP 2000,.1
1570 INPUT "2. X (in), (+ into flume)?",X_1
1580 BEEP 2500,.1
1590 INPUT "3. y (in), (+ along flume to the right)?",Y_1
1600 BEEP 3000,.1
1610 INPUT "4. z (in), (+ upward)?",Z_1
1620 !
1630 CALL Read_pot("X",Vx_1)
1640 CALL Read_pot("Y",Vy_1)
1650 CALL Read_pot("Z",Vz_1)
1660 !
1670 !
1680     CALL Clear_screen
1690 PRINT "C. Move the milling machine to a new"
1700 PRINT "     position in 3-D, by at least 5  "
1710 PRINT "     inches in each direction.      "
1720 BEEP 3200,.1
1730 INPUT "X, Y, Z in inches?",X_2,Y_2,Z_2
1740 CALL Read_pot("X",Vx_2)
1750 CALL Read_pot("Y",Vy_2)
1760 CALL Read_pot("Z",Vz_2)
1770 !
1780 ! C. Calculate the calibration coefficients
1790 !
1800     X_zero=-((Nozzle_od/2)+Vx_1*((X_2-X_1)/(Vx_2-Vx_1)))
1810     X_slope=(X_2-X_1)/(Vx_2-Vx_1)

```

```

1820      !
1830      Y_zero=-Vy_1*(Y_2-Y_1)/(Vy_2-Vy_1)
1840      Y_slope=(Y_2-Y_1)/(Vy_2-Vy_1)
1850      !
1860      Z_zero=-Vz_1*(Z_2-Z_1)/(Vz_2-Vz_1)
1870      Z_slope=(Z_2-Z_1)/(Vz_2-Vz_1)
1880      !
1890      !
1900      ! D. Find the physical boundaries for each
1910      !     direction.
1920      !
1930      CALL Clear_screen
1940      PRINT "1. Move the milling machine to the "
1950      PRINT "     minimum value of 'x'. Hit <cont>."
1960      PRINT "{Away from the flume, backwards}"
1970      PAUSE
1980      CALL Read_pot("X",V)
1990      X_min=X_zero+X_slope*V
2000      PRINT "2. Move the milling machine to the "
2010      PRINT "     maximum value of 'x'. {Towards "
2020      PRINT "     the flume}. Hit <cont>."
2030      PAUSE
2040      CALL Read_pot("X",V)
2050      X_max=X_zero+X_slope*V
2060      PRINT "3. Move the milling machine to the "
2070      PRINT "     minimum value of 'y'. Hit <cont>."
2080      PRINT "{To the left along the flume}"
2090      PAUSE
2100      CALL Read_pot("Y",V)
2110      Y_min=Y_zero+Y_slope*V
2120      PRINT "4. Move the milling machine to the "
2130      PRINT "     maximum value of 'y'. Hit <cont>."
2140      PAUSE
2150      CALL Read_pot("Y",V)
2160      Y_max=Y_zero+Y_slope*V
2170      PRINT "5. Move the milling machine to the "
2180      PRINT "     minimum value of 'z'. Hit <cont>."
2190      PRINT "{Downwards}"
2200      PAUSE
2210      CALL Read_pot("Z",V)
2220      Z_min=Z_zero+Z_slope*V
2230      PRINT "6. Move the milling machine to the "
2240      PRINT "     maximum value of 'z'. Hit <cont>."
2250      PAUSE
2260      CALL Read_pot("Z",V)
2270      Z_max=Z_zero+Z_slope*V
2280      !
2290      ! E. Write out the file "Motor_coef".
2300      !
2310      ON ERROR GOTO Purge_file
2320      Reenter: CREATE BDAT Filename$,1
2330      ASSIGN @File TO Filename$
2340      !
2350      OUTPUT @File;X_zero,X_slope
2360      OUTPUT @File;Y_zero,Y_slope
2370      OUTPUT @File;Z_zero,Z_slope
2380      !
2390      OUTPUT @File;X_min,X_max
2400      OUTPUT @File;Y_min,Y_max
2410      OUTPUT @File;Z_min,Z_max

```

```

2420      !
2430      ASSIGN @File TO *
2440      SUBEXIT
2450 Purge_file:  PURGE Filename$
2460                GOTO Reenter
2470      !
2480      SUBEND
2490      !
2500      !
2510      !
2520      !
2530      !
2540      !
2550      SUB Read_pot(Direction$,Value)
2560      !
2570      !
2580      ! Read one potentiometer and return a volt-
2590      ! age.
2600      !
2610      ! R3 -- Pot X
2620      ! R4 -- Pot Y
2630      ! R5 -- Pot Z
2640      !
2650      !
2660      IF Direction$="X" THEN Relay=3
2670      IF Direction$="Y" THEN Relay=4
2680      IF Direction$="Z" THEN Relay=5
2690      !
2700      !
2710      OUTPUT 723;"OP,1,0T"
2720      OUTPUT 723;"OB,1,";Relay;"",1T"
2730      !
2740      OUTPUT 723;"IP,3T"
2750      ENTER 72301;Value
2760      !
2770      !
2780      SUBEND
2790      !
2800      !
2810      !
2820      !
2830      !
2840      !
2850      SUB Clear_screen
2860      ! Clear the CRT.
2870      !
2880      OUTPUT 2 USING "#,B";255.75
2890      GCLEAR
2900      SUBEND
2910      !
2920      !
2930      !
2940      !
2950      !
2960      !
2970      SUB Motor(Direction$,Rotation$)
2980      !
2990      ! Turn on the motor in the requested direc-
3000      ! tion (x,y,z) with the requestion rota-
3010      ! tion (CW, CCW).

```

```

3020 !
3030   Dir$=Direction$
3040   Rot$=Rotation$
3050   IF Dir$="X" AND Rot$="CW" THEN Lbit=2
3060   IF Dir$="X" AND Rot$="CCW" THEN Lbit=1
3070   IF Dir$="Y" AND Rot$="CW" THEN Lbit=4
3080   IF Dir$="Y" AND Rot$="CCW" THEN Lbit=3
3090   IF Dir$="Z" AND Rot$="CCW" THEN Lbit=5
3100   IF Dir$="Z" AND Rot$="CW" THEN Lbit=6
3110   !
3120   !
3130   OUTPUT 723;"OP,7,";2^Lbit;"T"
3140 SUBEND
3150 !
3160 !
3170 !
3180 !
3190 !
3200 !
3210 SUB Motor_stop
3220 !
3230 !   Stop all motors!
3240 !
3250   OUTPUT 723;"OP,7,0T"
3260 SUBEND
3270 !
3280 !
3290 !
3300 !
3310 !
3320 !
3330 SUB Retrieve_coef(Coef(*),Filename$)
3340 !
3350   OPTION BASE 1
3360   !
3370   !   Retrieve the potentiometer calibration
3380   !   coefficients from a disk file called
3390   !   "Motor_coef". Place these in an array.
3400   !
3410   ASSIGN @File TO Filename$
3420   !
3430   FOR I=1 TO 12 STEP 2
3440     ENTER @File;Coef(I),Coef(I+1)
3450   NEXT I
3460   !
3470   ASSIGN @File TO *
3480 SUBEND
3490 !
3500 !
3510 !
3520 !
3530 !
3540 !
3550 SUB Label_point(X,Y,Z,Symbol$)
3560 !
3570 !   Label a point on the Flume diagram
3580 !   using the symbol specified.
3590 !
3600   PRINT TABXY(1,13);"(X,Y,Z) inches = ";
3610   PRINT USING "DDD.DDD";X,Y,Z

```



```

3620      !
3630      !
3640      IF Symbol$="X" THEN
3650      !
3660          MOVE 14+Y,24+Z
3670          IMOVE -.2,-.2
3680          IDRAW 0,.4
3690          IDRAW .4,0
3700          IDRAW 0,-.4
3710          IDRAW -.4,0
3720      !
3730      MOVE 14+Y,11+X
3740      IMOVE -.2,-.2
3750      IDRAW 0,.4
3760      IDRAW .4,0
3770      IDRAW 0,-.4
3780      IDRAW -.4,0
3790      END IF
3800      !
3810      IF Symbol$="+" THEN
3820      !
3830      MOVE 14+Y,11+X
3840      IMOVE 0,.2
3850      IDRAW -.2,-.4
3860      IDRAW .4,0
3870      IDRAW -.2,.4
3880      !
3890      MOVE 14+Y,24+Z
3900      IMOVE 0,.2
3910      IDRAW -.2,-.4
3920      IDRAW .4,0
3930      IDRAW -.2,.4
3940      END IF
3950      SUBEND
3960      !
3970      !
3980      !
3990      !
4000      !
4010      !
4020      SUB Move_ldv_to(X,Y,Z,Length_arm,Length_probe,Angle_arm,Angle_probe,C
    ))
4030      DEG
4040      !
4050      OUTPUT 723:"CC,1T"
4060      OUTPUT 723:"SF,3,3,3,1.25,12T"
4070      PRINTER IS 1
4080      ON KEY 0 LABEL "ABORT" CALL Stop_all
4090      OPTION BASE 1
4100      Tolerance=.006
4110      !
4120      !   Move the probe to the position indicated
4130      !   in (inches) relative to the nozzle tip.
4140      !
4150      !   Dimensions are in inches and degrees
4160      !
4170      !   A.1 Load in the calibration coefficients.
4180      !
4190      X_zero=Coef(1)
4200      X_slope=Coef(2)

```

```

4210      Y_zero=Coef(3)
4220      Y_slope=Coef(4)
4230      Z_zero=Coef(5)
4240      Z_slope=Coef(6)
4250      X_min=Coef(7)
4260      X_max=Coef(8)
4270      Y_min=Coef(9)
4280      Y_max=Coef(10)
4290      Z_min=Coef(11)
4300      Z_max=Coef(12)
4310      !
4320      ! A.2 Move the probe
4330      !
4340      CALL Probe_moe(Angle_probe)
4350      !
4360      ! B. Does (X,Y,Z) lie within the per-
4370      !      mitted boundaries?
4380      !
4390      IF X>X_max OR X<X_min OR Y>Y_max OR Y<Y_min OR Z>Z_max OR Z<Z_min THEN

4400          BEEP 1700,.5
4410          BEEP 2000,.5
4420          BEEP 1700,.5
4430          BEEP 2000,.5
4440          PRINT "Desired point is out of range!"
4450          SUBEXIT
4460      END IF
4470      !
4480      ! C. Find out where the probe is now, draw
4490      !      the flume on the CRT, and label the
4500      !      desired position.
4510      !
4520      ! 1. Sound warning, movement imminent!
4530      !
4540      CALL Clear_screen
4550      PRINT TABXY(1,12),"MOVEMENT OF MILLING MACHINE IMMINENT!!!"
4560      FOR I=1 TO 4
4570          BEEP 1200,.1
4580          BEEP 1700,.1
4590          BEEP 2200,.1
4600          BEEP 2700,.1
4610      NEXT I
4620      CALL Clear_screen
4630      !
4640      !
4650      OUTPUT 723;"CC,1T" !CLEAR RELAY CARD.
4660      CALL Position("X",X_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4670      CALL Position("Y",Y_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4680      CALL Position("Z",Z_actual,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
4690      !
4700      !
4710      CALL Draw_flume
4720      CALL Label_point(X_actual,Y_actual,Z_actual,"+")
4730      CALL Label_point(X,Y,Z,"X")
4740      !
4750      ! D. Move each motor to bring the error
4760      !      between actual and desired position

```

```

4770      !      into tolerance.
4780      !
4790      X_old=X_actual
4800 X_node: Xerror=X-X_actual
4810      IF ABS(Xerror)>Tolerance THEN
4820      IF Xerror>0 THEN Rot$="CCW"
4830      IF Xerror<0 THEN Rot$="CW"
4840      CALL Motor("X",Rot$)
4850      CALL Position("X",X_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
4860      CALL Plot_path(X_old,Y_actual,Z_actual,X_actual,Y_actual,Z_a
al)
4870      X_old=X_actual
4880      GOTO X_node
4890      END IF
4900      !
4910      !
4920      Y_old=Y_actual
4930 Y_node: Yerror=Y-Y_actual
4940      IF ABS(Yerror)>Tolerance THEN
4950      IF Yerror>0 THEN Rot$="CCW"
4960      IF Yerror<0 THEN Rot$="CW"
4970      CALL Motor("Y",Rot$)
4980      CALL Position("Y",Y_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
4990      CALL Plot_path(X_actual,Y_old,Z_actual,X_actual,Y_actual,Z_a
al)
5000      Y_old=Y_actual
5010      GOTO Y_node
5020      END IF
5030      !
5040      !
5050      Z_old=Z_actual
5060 Z_node: Zerror=Z-Z_actual
5070      IF ABS(Zerror)>Tolerance THEN
5080      IF Zerror>0 THEN Rot$="CW"
5090      IF Zerror<0 THEN Rot$="CCH"
5100      CALL Motor("Z",Rot$)
5110      CALL Position("Z",Z_actual,Valu_shaft,Length_arm,Length_probe,Angle_a
Angle_probe,Coef(*))
5120      CALL Plot_path(X_actual,Y_actual,Z_old,X_actual,Y_actual,Z_a
al)
5130      Z_old=Z_actual
5140      GOTO Z_node
5150      END IF
5160      !
5170      !
5180      CALL Motor_stop
5190      !
5200      !
5210      FOR I=1 TO 4
5220      BEEP 2400,.2
5230      BEEP 4800,.2
5240      NEXT I
5250      !
5260      SBEND
5270      !
5280      !
5290      !
5300      !

```

```

5310 !
5320 !
5330 SUB Position(Direction$,Value,Valu_shaft,Length_arm,Length_probe,Angle_arm,
Angle_probe,Coef(*))
5340 !
5350 OPTION BASE 1
5360 DEG
5370 !
5380 ! Return the position (inches) for the
5390 ! appropriate direction relative to the
5400 ! nozzle tip.
5410 !
5420 CALL Read_pot(Direction$,Voltage)
5430 !
5440 X_zero=Coef(1)
5450 X_slope=Coef(2)
5460 Y_zero=Coef(3)
5470 Y_slope=Coef(4)
5480 Z_zero=Coef(5)
5490 Z_slope=Coef(6)
5500 !
5510 !
5520 Dir$=Direction$
5530 !
5540 IF Dir$="X" THEN
5550 Valu_shaft=X_zero+X_slope*Voltage
5560 Value=Valu_shaft-Length_arm*COS(Angle_arm)*TAN(45-Angle_arm/2.0)
5570 END IF
5580 !
5590 IF Dir$="Y" THEN
5600 Valu_shaft=Y_zero+Y_slope*Voltage
5610 Value=Valu_shaft+Length_probe*(1.-COS(Angle_probe))*Length_arm*COS(
Angle_arm)
5620 END IF
5630 !
5640 IF Dir$="Z" THEN
5650 Valu_shaft=Z_zero+Z_slope*Voltage
5660 Value=Valu_shaft-Length_probe*SIN(Angle_probe)
5670 END IF
5680 !
5690 SUBEND
5700 !
5710 !
5720 !
5730 !
5740 !
5750 !
5760 SUB Stop_all
5770 ! STOP ALL MOTORS AND QUIT
5780 !
5790 GCLEAR
5800 CALL Motor_stop
5810 PRINT "MOTOR CONTROL ABORTED!!!"
5820 PRINT "(HIT <CONT> TO CONTINUE)"
5830 PAUSE
5840 SUBEND
5850 !
5860 !
5870 !
5880 !

```

```

5890 !
5900 !
5910 SUB Plot_path(X1,Y1,Z1,X2,Y2,Z2)
5920 !
5930 ! Plot the path of the probe on the flume
5940 ! diagram as the motors move the bed.
5950 !
5960 ! Lower plot followed by upper plot.
5970 !
5980 PRINT TABXY(1,13),"(X,Y,Z) inches = ";
5990 PRINT USING "DD.DDD";X2,Y2,Z2
6000 MOVE 14+Y1,24+Z1
6010 DRAW 14+Y2,24+Z2
6020 !
6030 MOVE 14+Y1,11+X1
6040 DRAW 14+Y2,11+X2
6050 !
6060 SUBEND

```



#### 4. T\_SUBS

```

10      ! T_SUBS
20      !
30      !
40      SUB T_couple(Temperature,Choice$,Scale$,No_readings,Stdev)
50      !
60      ! SUBPROGRAM T_COUPLE
70      !
80      ! by Bill Culbreth
90      ! 19 April 1984
100     !
110     ! PURPOSE: This program is designed to
120     !         read type T or E thermocouples and
130     !         return the actual temperature to
140     !         the calling routine.
150     !
160     ! Temperature -- Temperature from the
170     !         thermocouple in degrees F or C from
180     !         the thermocouple identified by
190     !         "Choice$".
200     ! Choice$ -- Thermocouple choice, current-
210     !         ly: "AMBIENT", "NOZZLE", or, "PROBE".
220     ! Scale$ -- "F" for Fahrenheit or "C" for
230     !         Celsius, or "H" for histogram in "C".
240     ! No_readings -- How many readings of the
250     !         same thermocouple should the routine
260     !         take?
270     ! Stdev -- The standard deviation of the
280     !         temperature for the indicated number
290     !         of readings in the units given by
300     !         "Scale$".
310     !
320     !
330     ! 1. Open all relays and initialize the
340     !     A/D converter.
350     !
360     OUTPUT 723;"CC,1T"
370     OUTPUT 723;"SF,3,3,3,1.25,12T"
380     !
390     OUTPUT 723;"OP,1,0T"
400     !
410     ! 2. Close the chosen relays.
420     !
430     !     a. Ambient T -- Type T, relays 6,8.
440     !     b. Nozzle T -- Type T, relays 7,8.
450     !     c. Probe T -- Type E, relay 9.
460     !
470     IF Scale$="H" THEN
480     ! Plot a histogram using Celsius.
490     Histogram$="YES"
500     Scale$="C"
510 ELSE
520     Histogram$="NO"
530 END IF
540 !
550 !
560 IF Choice$="AMBIENT" THEN
570     Type$="T"
580     OUTPUT 723;"OB,1,6,1,8,1T"
590 END IF
600 !

```

```

610     IF Choice$="NOZZLE" THEN
620         Type$="T"
630         OUTPUT 723;"OB,1,7,1,8,1T"
640     END IF
650     !
660     IF Choice$="PROBE" THEN
670         Type$="E"
680         OUTPUT 723;"OB,1,9,1T"
690     END IF
700     !
710     !
720     ! 3. Take an A/D conversion and convert
730     !     into temperature.
740     !
750     Sum=0
760     Sum1=0
770     !
780     WAIT 1
790     IF Histogram$="YES" THEN GOSUB Set_up_histo
800     !
810     !
820     FOR I=1 TO No_readings
830         OUTPUT 723;"IP,3T"
840         ENTER 72301:A
850         IF Type$="T" THEN
860             A=A/1000
870         END IF
880         IF Type$="E" THEN
890             A=A/1000
900         END IF
910         ! PRINT "V(mV) = ";A
920         GOSUB Convert_t
930         ! BEEP A*100,.01
940         Sum=Sum+A
950         Sum1=Sum1+A*A
960         !
970         IF Histogram$="YES" THEN GOSUB Plot_point
980         !
990     NEXT I
1000    !
1010    Temperature=Sum/No_readings
1020    !
1030    !
1040    IF No_readings=1 THEN
1050        Stdev=0
1060    ELSE
1070        Stdev=SQR(ABS((Sum1-No_readings*Temperature^2)/(No_readings-1)))
1080    END IF
1090    !
1100    ! 4. Open all relays.
1110    !
1120    OUTPUT 723;"OP,1,0T"
1130    !
1140    SUBEXIT
1150    !
1160    !
1170    !
1180    Convert_t: !
1190                ! This subroutine converts (mV)
1200                ! from a thermocouple into Temp-

```

```

1210             ! erature.
1220             !
1230             !
1240             IF Type$="I" THEN
1250                 A=2.5661297E+1*A-6.1954869E-1*A*A+2.2181644E-2*A^3-3.55009E-4*A^4
1260             END IF
1270             !
1280             !
1290             IF Type$="E" THEN
1300                 A=1.7022525E+1*A-2.2097240E-1*A*A+5.4809314E-3*A^3-5.7669892E-5*A^4
1310             END IF
1320             !
1330             !   Fix the scale.
1340             !
1350             IF Scale$="F" THEN A=1.8*A+32
1360             RETURN
1370             !
1380             !
1390             !
1400             !
1410             !
1420             !
1430 Set_up_histo: !
1440             !
1450             !   Set up a histogram of temperature
1460             !   versus number of counts.
1470             !
1480             !   1. Zero out the Height(*) array.
1490             !
1500             DIM Height(203)
1510             !
1520             FOR I=1 TO 202
1530                 Height(I)=0
1540             NEXT I
1550             !
1560             !
1570             DUMP DEVICE IS 701
1580             GINIT
1590             OUTPUT 2 USING "#,B";255,75
1600             GRAPHICS ON
1610             FRAME
1620             WINDOW -100,100,-10,100
1630             MOVE -65,92
1640             CSIZE 7
1650             LABEL "TEMPERATURE HISTOGRAM"
1660             AXES 25,10,0,0,4,5,3
1670             PEN -1
1680             MOVE 0,-10
1690             DRAW 0,0
1700             MOVE 0,90
1710             DRAW 0,100
1720             PEN 1
1730             !
1740             !   Take 10 temperature readings to get
1750             !   the scale.
1760             !
1770             Sum=0
1780             Sum1=0
1790             FOR I=1 TO 10
1800                 OUTPUT 723;"IP,3T"

```

```

1810         ENTER 72301:A
1820     NEXT I
1830     !
1840     FOR I=1 TO 100
1850         OUTPUT 723;"IP,3T"
1860         ENTER 72301:A
1870         IF Type$="T" THEN
1880             A=A/1000
1890         END IF
1900         IF Type$="E" THEN
1910             A=A/1000
1920         END IF
1930         GOSUB Convert_t
1940         Sum=Sum+A
1950         Sum1=Sum1+A*A
1960     NEXT I
1970     T_mean=Sum/100
1980     Sd=SQR(ABS(Sum1-100*T_mean^2)/99)
1990     !
2000     !   Change the window to extent from
2010     !       -4*Sd to +4*Sd.
2020     !
2030     MOVE -12,-7
2040     CSIZE 4
2050     LABEL USING "DDD.DD";T_mean
2060     MOVE 15,-7
2070     LABEL "C"
2080     !
2090     MOVE -87,-7
2100     LABEL USING "DDD.DD";T_mean-3*Sd
2110     MOVE 63,-7
2120     LABEL USING "DDD.DD";T_mean+3*Sd
2130     !
2140     !
2150     MOVE 5,47
2160     LABEL "50"
2170     !
2180     !
2190     !   3. Calculate the window temper-
2200     !       ature interval.
2210     !
2220     Interval=4*Sd/100
2230     !
2240     T_min=T_mean-4*Sd
2250     T_max=T_mean+4*Sd
2260     !
2270     WINDOW T_min,T_max,-10,100
2280     RETURN
2290     !
2300     !
2310     !
2320     !
2330     !
2340     !
2350     Plot_point: !
2360     !
2370     !   Plot each temperature point as
2380     !       received on the histogram.
2390     !
2400     Freq=((A-T_min)/(T_max-T_min))*3000+1000

```

```

2410      BEEP Freq,.01
2420      J=0
2430      !
2440      FOR T=T_min TO T_max STEP Interval
2450      J=J+1
2460      IF A<=T THEN
2470          Height(J)=Height(J)+1
2480          GOTO Continue
2490      END IF
2500      NEXT T
2510      !
2520      ! Draw the point.
2530      !
2540      Continue:      !
2550      !
2560      !
2570      MOVE A,Height(J)
2580      CSIZE 4
2590      LABEL "","
2600      !
2610      ! Label the number of points and
2620      ! the temperature.
2630      !
2640      PRINT TABXY(2,3);"T(C)=";A
2650      PRINT TABXY(2,5);"Sample #";I
2660      !
2670      RETURN
2680      !
2690      !
2700      !
2710      !
2720      !
2730      !
2740      SUBEND

```



## 5. T\_CAL

```

10      ! T_CAL
20      !
30      ! This program records the output from the
40      ! ambient, probe and nozzle thermocouples
50      ! for calibration purposes. The data is
60      ! printed as well as transmitted to a data
70      ! file.
80      !
90      ! Data is recorded in the following order:
100     !     a. Ambient temperature
110     !     b. Probe temperature
120     !     c. Nozzle temperature
130     !
140     ! Place the ambient, probe and nozzle
150     ! thermocouples into a bucket of warm water,
160     ! execute this program, then add ice.
170     !
180     !
190     LOADSUB ALL FROM "T_SUBS"
200     !
210     ! Identify the BDAT file
220     !
230     INPUT "NAME OF FILE WHERE DATA IS TO BE STORED?",Filename1$
240     !
250     ! Identify the number of data points desired
260     !
270     INPUT "NUMBER OF DATA POINTS DESIRED?",Nitems
280     !
290     ! Identify the number of samples per
300     ! thermocouple per data point
310     !
320     INPUT "NUMBER OF SAMPLES PER DATA POINT?",Sample
330     !
340     ! Initialize a counter
350     !
360     I=1
370     !
380     ! Create a data file
390     !
400     Records=(Nitems*8*3/256)+2
410     CREATE BDAT Filename1$,Records
420     ASSIGN @File1 TO Filename1$
430     !
440     ! Take data and print results
450     !
460     CALL T_couple(T_ambient,"AMBIENT","C",Sample,Sd)
470     BEEP T*50,.05
480     PRINT "TAMB,SD=";T_ambient,Sd
490     CALL T_couple(T,"PROBE","C",Sample,St_dev)
500     BEEP T*50,.05
510     PRINT "TPROBE,SD=";T,St_dev
520     CALL T_couple(T_nozzle,"NOZZLE","C",Sample,Sd)
530     BEEP T*50,.05
540     PRINT "TNOZL,SD=";T_nozzle,Sd
550     !
560     ! Send data to the data file
570     !
580     OUTPUT @File1;T_ambient,T,T_nozzle
590     !
600     ! Test to see if finished

```

```
610 !
620 IF I=Nitems THEN
630     GOTO 760
640 ELSE
650     I=I+1
660     GOTO 460
670 END IF
680 !
690 !   Close the data file
700 !
710 OUTPUT @File1;-100
720 ASSIGN @File1 TO *
730 !
740 !   Alert the user...the job is completed
750 !
760 PRINT "ALL DONE"
770 BEEP
780 BEEP
790 END
```

## 6. PROBE\_CAL

```
10      ! PROBE_CAL
20      !
30      ! This program will provide the data
40      ! necessary to calibrate probe deflection
50      ! if used in the following manner:
60      !
70      ! a. Switch OFF probe actuation power
80      ! at the probe base.
90      !
100     ! b. Swing the probe arm out of the
110     ! tank such that the probe is
120     ! accessible.
130     !
140     ! c. Attach the calibration panel to the
150     ! probe assembly, taking care not to
160     ! damage the glass probe.
170     !
180     ! d. Run the program...it will ask for
190     ! the desired position in mV. The
200     ! following guidelines apply:
210     !
220     !     i. If it is desired to lower
230     !         the probe, type the extreme
240     !         value 9000 (anything >4600
250     !         will work, but 9000 is a
260     !         quick and easy number to
270     !         enter).
280     !
290     !     ii. If it is desired to raise
300     !          the probe, enter the extreme
310     !          value 90 (anything less than
320     !          940 will work).
330     !
340     ! e. The program will next ask which bit
350     ! is selected to be "high". The
360     ! following guidelines apply:
370     !
380     !     i. If it is desired to lower the
390     !         probe, enter 7.
400     !
410     !     ii. If it is desired to raise the
420     !          probe, enter 8.
430     !
440     ! f. Switch ON probe activation power and
450     ! when the probe reaches a desired'
460     ! degree of deflection, switch the
470     ! activation power OFF and record the
480     ! mV value printed on the screen.
490     !
500     ! g. Repeat steps (d) through (f) until
510     ! sufficient data is collected. Load
520     ! this data into the program "POLYFIT"
530     ! and request a second order fit
540     ! (let X=angle and Y=mV).
550     ! Enter the coefficients derived by
560     ! this program into the appropriate
570     ! location in the program "PROBE_SUBS".
580     !
590     !
600     ! NOTE: The relays will be activated on
```

```

610 !      digital low!  When the machine boots
620 !      up (hp-9826), all relay lines are
630 !      high (+5V).  The instructions below
640 !      will drop the voltage to zero.
650 !
660 INPUT "What is the desired position? (mV)",Voltage
670 PRINT "Desired position (mV) =";Voltage
680 !
690 !Read the actual motor position.
700 !  If the desired position is BELOW the
710 !  actual position, then tell the motor
720 !  to move UP.
730 !  If it is ABOVE, then tell it to go DOWN.
740 !
750 !
760 INPUT "WHICH BIT DO YOU WANT HIGH?",Lbit
770 !
780 !
790   OUTPUT 723;"OP,7,0T" !CLEAR ALL D/O
800   OUTPUT 723;"OP,7,";2^Lbit;"T"
810 !
820   OUTPUT 723;"CC,1T" !CLEAR A/D CARD
830 !
840   OUTPUT 723;"SF,3,3,3,1.25,12T" !FORMAT A/D
850   OUTPUT 723;"OB,1,10,1T" !CLOSE THE RELAY
860                               !THAT CONNECTS THE
870                               !A/D CARD TO THE
880                               !POTENTIOMETER
890   OUTPUT 723;"IP,3T" !START A/D CONVERSION
900   ENTER 72301;A      !ENTER A/D VALUE INTO A.
910   DISP A
920   BEEP ABS(A),.01
930 !
940 !   The following IF stops the motor when
950 !   it reaches it's limits.
960 !
970   IF (Lbit=7 AND A>4600) OR (Lbit=8 AND A<940) THEN
980       OUTPUT 723;"OP,7,0T"
990       BEEP
1000      PRINT "ALL DONE!!!"
1010   END IF
1020   GOTO 890
1030   END

```

## 7. MOTOR\_CAL

```

10  !   MOTOR_CAL
20  !
30  !   PURPOSE: Calibrate the potentiometers
40  !       used with the motors on the milling
50  !       machine.
60  !
70  !
80  !   OPTION BASE 1
90  !   DIM Coef(12)
100 !
110 !   OUTPUT 723;"SF.3.3.3.1.25.12T"
120 !   LOADSUB ALL FROM "MTR_SUBS"
130 !   LOADSUB ALL FROM "PROBE_SUBS"
140 !   File$="motor_coef"
150 !
160 !   CALL Calibrate(File$)
170 !
180 !   CALL Retrieve_coef(Coef(*),File$)
190 !   BEEP 2400,1
200 !
210 !
220 !   PRINT "What (x,y,z) position do you wish to"
230 !   PRINT "       move to? (inches relative to noz-"
240 !   PRINT "       zle)"
250 !   INPUT X,Y,Z
260 !
270 !   CALL Move_ldv_to(X,Y,Z,Length_arm,Length_probe,Angle_arm,Probe_angle,Coe
280 !   *)
290 !   BEEP
300 !   GOTO 280
310 !   END

```



## 8. LOAD\_XYZ

```

10  ! LOAD_XYZ
20  !
30  ! by Bill Culbreth
40  !
50  ! 30 April 1984
60  !
70  !
80  ! PURPOSE: This program will allow the
90  ! user to enter desired (x,y,z) posi-
100 ! tions of the milling machine relative
110 ! to the nozzle. The values will be
120 ! stored on disk to be utilized later
130 ! by MAIN_T.
140 !
150 DIM X(500),Y(500),Z(500)
160 !
170 ! 1. Input the file name.
180 !
190 GOSUB Clear_screen
200 !
210 PRINTER IS 1
220 PRINT "Input the file name."
230 PRINT "{ I suggest 'RUNXX' where 'XX'"
240 PRINT " is the run number.      }";
250 PRINT
260 INPUT Filename$
270 !
280 !
290 ! 2. Begin inputting data.
300 !
310 !
320 GOSUB Clear_screen
330 !
340 PRINT "Do you wish to append a previous data file?"
350 INPUT Answer$
360 !
370 IF Answer$="YES" THEN
380     INPUT "Previous file name?",Old_file$
390     ASSIGN @File1 TO Old_file$
400     !
410     I=0
420 Loop1: !
430     I=I+1
440     ENTER @File1:X(I),Y(I),Z(I)
450     OUTPUT 701:"I,X,Y,Z=";I,X(I),Y(I),Z(I)
460     IF X(I)<>-100 THEN GOTO Loop1
470     ASSIGN @File1 TO *
480     PURGE Old_file$
490     Count=I-1
500 ELSE
510     Count=0
520 END IF
530 !
540 GOSUB Clear_screen
550 BEEP
560 !
570 PRINT "1. Input the desired position in "
580 PRINT " inches as X, Y, and Z."
590 PRINT
600 PRINT "2. Terminate input by entering '-100'"

```

```

610     PRINT "2. Terminate input by entering '-100'"
620     PRINT "    for X, Y, and Z."
630     PRINT "3. If you wish to enter an orientation angle,"
640     PRINT "    enter '-999,orientation,0'."
650     PRINT
660     !
670 Begin: !
680     Count=Count+1
690     PRINT "Item #":Count
700     INPUT "(X,Y,Z) in inches?",X(Count),Y(Count),Z(Count)
710     OUTPUT 701;"I,X,Y,Z=";Count,X(Count),Y(Count),Z(Count)
720     IF X(Count)<>-100 THEN GOTO Begin
730     !
740     End_count=Count-1
750     !
760     ! All data points have been entered.
770     !
780     ! a. Set up new softkeys.
790     ! b. Explain softkeys.
800     !
810     GOSUB Clear_screen
820     !
830     PRINT "SOFTKEY LABELS:"
840     PRINT "  0 -- WRITE data to disk."
850     PRINT "  2 -- EDIT out bad data."
860     PRINT "  4 -- HARD copy the data on printer."
870     PRINT "  6 -- LIST data on the CRT."
880     PRINT "  8 -- STOP terminates the program."
890     !
900     ON KEY 0 LABEL "WRITE" GOSUB Write_data
910     ON KEY 2 LABEL "EDIT" GOSUB Edit_data
920     ON KEY 4 LABEL "HARD" GOSUB Hard_copy
930     ON KEY 6 LABEL "LIST" GOSUB List_data
940     ON KEY 8 LABEL "STOP" GOTO Terminate
950     GOTO 900
960     !
970     !
980     !
990     !
1000    !
1010    !
1020    !
1030 Clear_screen: !
1040    !
1050    ! Clear the CRT display.
1060    !
1070    OUTPUT 2 USING "#,B";255,75
1080    GCLEAR
1090    RETURN
1100    !
1110    !
1120    !
1130    !
1140    !
1150    !
1160 Hard_copy: !
1170    !
1180    ! Print out all data to the printer.
1190    !
1200    PRINTER IS 701

```

```

1210      !
1220      PRINT "   Count      X(inches)      Y(count)      Z(count)"
1230      PRINT "   _____      _____      _____      _____"
1240      PRINT
1250      FOR I=1 TO End_count
1260      PRINT I,X(I),Y(I),Z(I)
1270      NEXT I
1280      !
1290      PRINTER IS 1
1300 RETURN
1310 !
1320 !
1330 !
1340 !
1350 !
1360 !
1370 List_data: !
1380 !
1390 ! List data to the CRT.
1400 !
1410 GOSUB Clear_screen
1420 !
1430 PRINT "There are";End_count;" data points."
1440 PRINT
1450 INPUT "Which point do I start with?",Start
1460 INPUT "Which point do I end with?",End_data
1470 !
1480 FOR I=Start TO End_data
1490 PRINT "I,X,Y,Z=";I,X(I),Y(I),Z(I)
1500 NEXT I
1510 RETURN
1520 !
1530 !
1540 !
1550 !
1560 !
1570 !
1580 Edit_data: !
1590 !
1600 ! Edit data.
1610 !
1620 GOSUB Clear_screen
1630 !
1640 INPUT "Which data point do you wish to alter?",I
1650 !
1660 PRINT
1670 PRINT "For point #";I;" (X,Y,Z) where:"
1680 PRINT X(I);",";Y(I);",";Z(I)
1690 !
1700 INPUT "Type in the new values:",X(I),Y(I),Z(I)
1710 RETURN
1720 !
1730 !
1740 !
1750 !
1760 !
1770 !
1780 Write_data: !
1790 !
1800 ! Write data out to a file on disk.

```

```

1810      !
1820      X(End_count+1)=-100
1830      Y(End_count+1)=-100
1840      Z(End_count+1)=-100
1850      !
1860      Max_data=3*(End_count+1)
1870      !
1880      File_size=INT(Max_data*8/256)+1
1890      !
1900      CREATE BDAT Filename$,File_size
1910      ASSIGN @File TO Filename$
1920      !
1930      FOR I=1 TO End_count+1
1940          OUTPUT @File;X(I),Y(I),Z(I)
1950      NEXT I
1960      !
1970      GOSUB Clear_screen
1980      BEEP 2400,.3
1990      PRINT "File ";Filename$;" has been stored!"
2000      ASSIGN @File TO *
2010      RETURN
2020      !
2030      !
2040      !
2050      !
2060      !
2070      !
2080      Terminate: !
2090          GOSUB Clear_screen
2100          PRINT "NORMAL TERMINATION OF PROGRAM!"
2110      END

```

## 9. SEND\_DATA

```

10      !      SEND_DATA
20      !
30      !      To VAX,IBM,TRS-80.
40      !
50      !      HP-9826 TERMINAL PROGRAM
60      !      [REQUIRES BINARY ENHANCEMENT PROGRAM
70      !      "BEB"! ]
80      !
90      !      JUNE 30, 1982
100     !      updated 1/5/83
110     !      updated 1/16/84
120     !
130     !      BILL CULBRETH
140     !
150     !
160     Sc=9      ! RS-232 IS SELECT CODE 9.
170     PRINTER IS 1 ! PRINTER IS CRT.
180     Pr=1      ! DEFAULT PRINTER IS CRT
190     Printer_choice=701 ! MY PRINTER IS 701.
200     Bits=7    ! BITS PER CHARACTER
210     Duplex=0   ! FULL DUPLEX
220     Baud=300   ! BAUD RATE
230     Computer=1 ! ASSUME IBM COMPUTER
240     !
250     OUTPUT Pr;"(300 BAUD, IBM assumed."
260     OUTPUT Pr;" Load the binary program BEB first"
270     OUTPUT Pr;" unless you have BASIC 2.0"
280     OUTPUT Pr;" SET MODEM ON <FULL DUPLEX> )"
290     OUTPUT Pr;" "
300     !
310     DIM Name$(200),Hp_file$(30),Aa(1500),Numb$(30)
320     INTEGER Isend
330     !
340     CONTROL Sc,3:Baud
350     CONTROL Sc,4:Bits-5+4 ! BITS/CHAR & #STOP BITS.
360     !
370     !
380     To_disk=0
390     Datadump=0
400     I_data=1
410     I=1
420     J=1
430     K=1
440     L=1
450     !
460     ON ERROR GOTO Errors
470     ON KEY 0 LABEL "Line Mode" GOTO Line_mode
480     ON KEY 5 LABEL "Terminal" GOTO Terminal
490     ON KEY 6 LABEL "To Crt" GOTO Pr_crt
500     ON KEY 7 LABEL "To Prt" GOTO Pr_prt
510     ON KEY 8 LABEL "DATA" GOTO Data_dump
520     !
530     !
540     Line_mode:      !
550         OUTPUT Pr;"(LINE RECEPTION MODE)"
560     Begin: STATUS Sc,10;Y ! CHECK FOR FULL BUFFER
570     *
580         IF BIT(Y,0)=0 THEN GOTO Begin
590     !
600     ! RECEIVE ROUTINE.

```



```

610      !
620 Receive:      STATUS Sc,6;A
630      B=A
640      OUTPUT Pr USING "#,A";CHR$(B)
650      IF B=63 AND Datadump=1 THEN GOTO Data_dump
660      IF B=13 AND Computer=3 THEN OUTPUT Pr;CHR$(13)
670      GOTO Begin
680      !
690      !   TRANSMIT ROUTINE.
700      !
710*
720      IF Duplex=0 THEN
730          IF NUM(Key$)<>255 THEN OUTPUT Pr USING "#,A";Key$
740          IF NUM(Key$)=255 THEN OUTPUT Pr;" "
750      END IF
760      IF Computer=1 AND NUM(Key$)=8 THEN Key$=CHR$(64)
770      !
780      !   the previous line gives an @
790      !   for a backspace for the IBM.
800      !
810      IF Computer=5 AND NUM(Key$)=8 THEN Key$=CHR$(127)
820      !
830      !   THE VAX/VMS REQUIRES A DELETE
840      !   SYMBOL FOR A BACKSPACE.
850      !
860      IF NUM(Key$)=255 THEN Key$=CHR$(13)
870      OUTPUT Sc USING "#,A";Key$
880      GOTO Begin
890      !
900      !
910      !
920      !   DATA FILE OUT TO THE HOST COMPUTER.
930      !
940      !
950      !
960 Data_dump:      !
970      IF I_data=1 THEN GOSUB Open_file
980      !
990      IF Datadump=0 THEN GOTO Begin
1000      IF Computer=1 THEN WAIT .3
1010      ! wait for the slow IBM.
1020      BEEP 1000+RND*1500,.05
1030      OUTPUT Pr;"A(";I_data;")=";
1040      OUTPUT Pr;Aa(I_data)
1050      GOSUB Send_number
1060      IF Aa(I_data)=-200 THEN
1070          I_data=1
1080          Datadump=0
1090      END IF
1100      I_data=I_data+1
1110 GOTO Begin
1120      !
1130      !
1140      !   ERROR HANDLING SUBROUTINE
1150      !
1160 Errors:      OFF ERROR
1170      Close_file=-200
1180      ! FIRST, END OF FILE ERROR.
1190      IF ERRN=59 THEN
1200          Aa(I)=-200

```

```

1210             GOTO 2000 ! RETURN AFTER ERROR.
1220         END IF
1230         !
1240         IF ERRN<>59 THEN OUTPUT Pr;"<error #";ERRN;" generated.>"
1250         IF ERRN=54 THEN OUTPUT Pr;"(FILE <;Hp_file$;"> ALREADY THERE)"
1260         IF ERRN=54 THEN GOTO Created
1270         IF ERRN=56 THEN OUTPUT Pr;"<FILE <;Hp_file$;" IS NOT ON DISK.>"
1280         ASSIGN @File TO *
1290 GOTO Line_mode
1300 !
1310 !
1320 ! OUTPUT TO CRT.
1330 !
1340 Pr_crt: Pr=1
1350         GOTO Line_mode
1360 !
1370 !
1380 ! OUTPUT TO PRINTER.
1390 !
1400 Pr_prt: Pr=Printer_choice
1410 GOTO Line_mode
1420 !
1430 !
1440 ! CHANGE THE TERMINAL CHARACTERISTICS.
1450 !
1460 Terminal: !
1470         OUTPUT Pr;"      1. Baud Rate =";Baud
1480         OUTPUT Pr;"      2. Bits/Char =";Bits
1490         OUTPUT Pr;"      3. Duplex      =";Duplex
1500         OUTPUT Pr;"      [1=full,0=half]"
1510         OUTPUT Pr;"      4. Computer  =";Computer
1520         OUTPUT Pr;"      [IBM=1, VAX/UNIX=2, "
1530         OUTPUT Pr;"      TRS-80=3, Cyber=4, vax/vms=5]"
1540         OUTPUT Pr;" "
1550         INPUT "Change which one?",Which
1560         IF Which=1 THEN INPUT "To?",Baud
1570         IF Which=2 THEN INPUT "To?",Bits
1580         IF Which=3 THEN INPUT "To?",Duplex
1590         IF Which=4 THEN INPUT "To?",Computer
1600         IF Computer=1 THEN Duplex=0
1610         IF Computer=3 THEN Duplex=0
1620         IF Computer=3 THEN Bits=8
1630         IF Computer=5 THEN Duplex=1
1640 GOTO Line_mode
1650 !
1660 !
1670 !
1680 Open_file: !
1690         ! Open a file to read data from
1700         ! disk.
1710         !
1720         Datadump=1
1730         !
1740         INPUT "Is this LDV data? (1=YES)".Ldv$
1750         IF Ldv$="1" THEN
1760             INPUT "Experiment #?".Experiment$
1770         ELSE
1780             OUTPUT Pr;"Data file out of HP to host."
1790             INPUT "File name?",Hp_file$
1800         END IF

```

```

1810      !
1820      IF Ldv$="1" THEN
1830      Hp_file$=Experiment$&"_RESULT"
1840      END IF
1850      !
1860      ! Read the file off of disk.
1870      !
1880      ASSIGN @File TO Hp_file$
1890      I=1
1900      Check=0
1910      BEEP
1920      BEEP
1930      OUTPUT Pr;"(Working on file <"Hp_file$;">.)"
1940      !
1950 *
1960      ENTER @File;Aa(I)
1970      Check=Aa(I)
1980      I=I+1
1990 *
2000      !
2010      ASSIGN @File TO *
2020      Datadump=1
2030      RETURN
2040      !
2050      !
2060      !
2070      Send_number: !
2080      ! SEND A NUMBER ONE CHARACTER AT
2090      ! A TIME TO THE HOST COMPUTER.
2100      !
2110      Numb$=VAL$(Aa(I_data))
2120      Length=LEN(Numb$)
2130      !
2140      IF ((Ldv$="1") AND (I_data>13)) THEN
2150      Posit=POS(Numb$,".")
2160      IF (Posit<>0) THEN Length=Posit+2
2170      END IF
2180      !
2190      FOR I=1 TO Length
2200      Numeric=NUM(Numb$[I,I])
2210      OUTPUT Sc USING "#,A";Numb$[I,I]
2220      NEXT I
2230      !
2240      OUTPUT Sc USING "#,A";CHR$(13)
2250      RETURN
2260      !
2270      !
2280      !
2290      END

```

## APPENDIX C

## MAINFRAME PROGRAMS

1. TCAL

TCAL

PURPOSE: THIS PROGRAM PLACES THERMOCOUPLE CALIBRATION DATA RECEIVED FROM THE HP-9826 MICROCOMPUTER INTO A MORE WORKABLE FORMAT FOR USE IN THE PROGRAM TFIT.

DIMENSION TPROBE(200),TAME(200),TNOZZ(200)

$$1 = 1$$

```

10 READ(07,*) TAMB(1)
   IF(TAMB(1).EQ.-200.0) GO TO 20
   READ(07,*) TPROBE(1)
   READ(07,*) TNOZZ(1)
   NITE45=1

```

$$I = I_0 + I_1$$

GO TO 10

20 CONTINUE

WHITE (5,40)

DO 30 I=1,NITEMS

```
WRITE(6,50)1,TAMB(1),TPROBE(1),TNOZZ(1)
```

30 CONTINUE

```

FORMAT (BX, 'AMBIENT (C)', 2X, 'PROBE (C)', 2X, 'NOZZLE (C)')

```

```
50 FORMAT(1X,13,0X,2(F6.3,0X))
```

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END

## 2. TFIT

```

C
C
C      TFIT
C
C      PURPOSE:  THIS PROGRAM PERFORMS A FIRST ORDER CURVE FIT BY THE
C                  LEAST SQUARES METHOD FOR TWO COLUMNS OF DATA.  THE
C                  FIRST COLUMN LISTS VALUES OF X AND THE SECOND LISTS
C                  VALUES OF F(X) OR Y.  FOR THERMOCOUPLE CALIBRATION,
C                  LET X = THE AMBIENT TEMPERATURE, AND LET Y = EITHER
C                  THE PROBE OR NOZZLE TEMPERATURE AS DESIRED.
C
C
C      DIMENSION X(150),Y(150),XSQ(150),XY(150),YEST(150)
C      SUMX=0.0
C      SUMXSQ=0.0
C      SUMXY=0.0
C      SUMY=0.0
C      SUMNUM=0.0
C      SUMDEN=0.0
C      READ(7,*)NITEMS
C      DO 10 I=1,NITEMS
C        READ(7,*)X(I),Y(I)
C        XSQ(I)=X(I)**2
C        XY(I)=X(I)*Y(I)
C        SUMX=SUMX+X(I)
C        SUMXSQ=SUMXSQ+XSQ(I)
C        SUMXY=SUMXY+XY(I)
C        SUMY=SUMY+Y(I)
C 10  CONTINUE
C      XITEMS=FLOAT(NITEMS)
C      A=(SUMY*SUMXSQ-SUMX*SUMXY)/(XITEMS*SUMXSQ-SUMX**2)
C      B=(XITEMS*SUMXY-SUMX*SUMY)/(XITEMS*SUMXSQ-SUMX**2)
C      YBAR=SUMY/XITEMS
C      DO 20 I=1,NITEMS
C        YEST(I)=B+X(I)*A
C      *WRITE(6,*)YEST(I),Y(I)
C        SUMNUM=SUMNUM+(YEST(I)-YBAR)**2
C        SUMDEN=SUMDEN+(Y(I)-YBAR)**2
C 20  CONTINUE
C      RSQ=SUMNUM/SUMDEN
C      *WRITE(6,*)A,B,RSQ
C      STOP
C      END

```



### 3. JETCURV

[illegible]

#### 4. GRAB

```

C
C      GRAB
C
C      PURPOSE:  DATA TRANSFER FROM THE HP-9826MICROCOMPUTOR
C                TO THE IBM.
C
C      BY BILL CULBRETH
C      FOR ME2410, FALL QUARTER, 1982
C
C      FILEDEF 05 TERMINAL
C      FILEDEF 06 TERMINAL
C      FILEDEF 07 DISK MYDATA DATA (PERM)
C
C      GLOBAL TXLIB FORTRMOD2 MOD2EEH
C
C      TYPE IN THE ABOVE 4 LINES TO MAKE THIS
C      FORTRAN PROGRAM RUN.
C
C      DIMENSION DATA(3000)
C      I=1
C      WRITE(6,80)
80    FORMAT(2X,'BEGIN INPUTING DATA FROM THE HP-9826')
C
C      10    CONTINUE
C           READ(5,*) DATA(I)
C           I=I+1
C           IF(DATA(I-1).NE.-200) GOTG 10
C
C           NITEMS = I-1
C           6    FORMAT(2X,'5.' DATA POINTS WERE ENTERED.')
C           WRITE(6,6) NITEMS
C
C           NOW THAT ALL DATA HAS BEEN ENTERED, WRITE IT OUT ON
C           DISK.
C           5    FORMAT(2X,'DATA('5.'15.') = '5.'15.5)
C           I=1
C           20    WRITE(7,*) DATA(I)
C           I=I+1
C           IF(DATA(I-1).NE.-200) GOTG 20
C
C           ALL DATA HAS BEEN WRITTEN ONTO DISK.
C
C      STOP
C      END

```

## 5. TDATA

```

C
C
C      TDATA
C
C      PURPOSE:  THIS PROGRAM PLACES THE RUCYANT JET DATA RECEIVED
C                FROM THE HP-9826 MICROCOMPUTER INTO A MORE ORDERLY
C                FORMAT.  IT ALSO CONVERTS UNITS OF LENGTH FROM SI
C                TO METRIC.
C
      DIMENSION X(200),Y(200),Z(200),TPROBE(200),TAMB(200),TNOZZ(200),
      I(STDEV(200),XMM(200),YMM(200),ZMM(200)
      I=1
10  READ(07,2) X(I)
      IF(X(I).EQ.-200.0) GO TO 20
      XMM(I)=25.4*X(I)
      READ(07,2) Y(I)
      YMM(I)=25.4*Y(I)
      READ(07,2) Z(I)
      ZMM(I)=25.4*Z(I)
      READ(07,2) TPROBE(I)
      READ(07,2) TAMB(I)
      READ(07,2) TNOZZ(I)
      READ(07,2) STDEV(I)
      NITEMS=(
      I=I+1)
      GO TO 10
20  CONTINUE
      WRITE(6,40)
      DO 30 I=1,NITEMS
        WRITE(6,50) (XMM(I),YMM(I),ZMM(I),TPROBE(I),TAMB(I),TNOZZ(I),
      I(STDEV(I)
30  CONTINUE
40  FORMAT(8X,'X (MM)',4X,'Y (MM)',4X,'Z (MM)',2X,'PROBE (C)',X,
      I,'AMBIENT (C)',X,'NOZZLE (C)',X,'STDEV (C)')
50  FORMAT(1X,1J,3X,2(F7.3,3X),F7.3,4X,4(F6.3,4X))
      STOP
      END

```

## 6. CONTOUR4

```

C
C      CONTOUR4
C
C      PURPOSE:  THIS PROGRAM IS DESIGNED TO DISPLAY BUOYANT JET
C                 TEMPERATURE DATA USING A CONTOUR PLOTTING PACKAGE
C                 AVAILABLE WITH DISPLA. THE FOLLOWING RAW DATA IS
C                 READ FROM A DISK FILE: PROBE POSITIONS IN XYZ
C                 COORDINATES RELATIVE TO THE NOZZLE TIP, AMBIENT
C                 TEMPERATURE, PROBE TEMPERATURE AND NOZZLE TEMPERATURE.
C                 THE PROBE AND NOZZLE TEMPERATURES ARE TRANSFORMED
C                 BY CALIBRATION COEFFICIENTS AND NORMALIZED WRT AMBIENT
C                 TEMPERATURE. THE XYZ COORDINATES ARE CONVERTED TO
C                 X-S* COORDINATES RELATIVE TO THE INTERSECTION OF THE
C                 DATA PLANE WITH THE CENTERLINE TRAJECTORY OF THE JET
C                 (THE S-AXIS IS TANGENT TO THE TRAJECTORY). THIS
C                 PROGRAM ALSO COMPUTES THE RATE OF HEAT TRANSFER FROM
C                 THE JET TO THE AMBIENT.
C
C                 NOTE: THE FOLLOWING VALUES MUST BE INSERTED AS THE
C                 FIRST LINE OF DATA IN FREE FORMAT: THE TOTAL NUMBER
C                 OF DATA POINTS (NITEMS), THE ACUTE ANGLE BETWEEN
C                 THE DATA PLANE AND HORIZONTAL (THETA) AND THE VERTICAL
C                 DISTANCE BETWEEN THE Z-AXIS AND THE INTERSECTION
C                 POINT DISCUSSED ABOVE (ZA), THE CENTERLINE VELOCITY
C                 IN M/S (VEL) AND JET WIDTH IN MM (WIDTH).
C
C      DIMENSION X(100),Y(100),T(100),TP(100),TA(100),TN(100),TMAT(10,10)
C      COMMON /DRK(16000)
C
C      * * * READ DATA FROM UNIT "7" DISK * * *
C
C      READ(7,*) NITEMS,THETA,ZA,VEL,WIDTH
C
C      DO 20 I=1,NITEMS
C        READ(7,*) A,X(I),A,Y(I),TP(I),TA(I),TN(I),A
C          Y(I) = (Y(I)-ZA)/SIN(THETA)
C
C          CALIBRATION COEFFICIENTS
C          TP(I) = .984809875*TP(I) + 1.74079605
C          TN(I) = .933223426*TN(I) + 1.84754086
C
C          T(I) = (TP(I) - TA(I))/(TN(I) - TA(I))
C
C      20 CONTINUE
C
C      30 FORMAT(2X,'I,X,Y,T',15,3F15.5)
C
C      * * * DIMENSION OF TMAT * * *
C
C      IXDIM = 10
C      IYDIM = 10
C
C
C      * * * FIND THE MAXIMUM AND MINIMUM TEMPERATURES * * *
C
C      TMIN = 100.0
C      TMAX = 0.0
C      XMAX = 0.0
C      YMAX = 0.0
C      XMIN = 100.0
C      YMIN = 100.0
C
C      DO 40 I=1,NITEMS
C        IF(T(I) .GT. TMAX) TMAX = T(I)
C        IF(T(I) .LT. TMIN) TMIN = T(I)

```

```

      IF(X(I).GT.XMAX)XMAX=X(I)
      IF(Y(I).GT.YMAX)YMAX=Y(I)
      IF(X(I).LT.XMIN)XMIN=X(I)
      IF(Y(I).LT.YMIN)YMIN=Y(I)
40  CONTINUE
C
C* * * DETERMINE THE MAXIMUM VALUES OF X AND Y WITHIN A
C  QUADRANT, ASSUMING THE STREAMWISE AXIS IS CENTERED
C  IN A SQUARE MATRIX PLANE
C
      DX=((XMAX-XMIN)/FLOAT(IXDIM))/1000.
      DY=((YMAX-YMIN)/FLOAT(IYDIM))/1000.
      QUADX=(FLOAT(IXDIM)/2.0)*CX
      QUADY=(FLOAT(IYDIM)/2.0)*CY
C
C* * * FIND THE INCREMENTAL AREA FOR HEAT TRANSFER CALCULATIONS * * *
C
      AREA=DX*DY
C
C* * * ESTABLISH THE INCREMENT SIZE FOR CONTOUR PLOTS * * *
C
      TINC=(TMAX-TMIN)/5.25
C
C* * * GENERATE THE GRID * * *
C
      CALL COMPRS
      CALL TEK618
      CALL PAGE(8.,9.)
      CALL BLUWUP(0.75)
      CALL PHYSOR(1.25,1.)
      CALL AREA2DIS(5.5,5.5)
C
      CALL HEIGHT(0.100)
      CALL CARTUG
      CALL INTAXS
      CALL XNAME('X (MM)',$$,100)
      CALL YNAME('Y (MM)',$$,100)
      CALL XTICKS(2)
      CALL YTICKS(2)
      CALL YAXANG(90.0)
C
C
C
      CALL SWISSM
      CALL HEADIN('TEMPERATURE CONTOURS IN A BUOYANT JET',$$,100,2.,4)
      CALL HEADIN('WITH A CROSSFLOWING AMBIENT',$$,100,2.,4)
      CALL HEADIN('125% FLOW RATE',$$,100,1.,4)
      CALL HEADIN('PLANE A',$$,100,1.,4)
      CALL GRAF(-30.0,05.0,30.0,-30.0,05.0,30.0)
C
C* * * GENERATE THE INTERPOLATED TEMPERATURE MATRIX "TMAT" * * *
C
      CALL BCUMUN(1000)
      CALL ZBASE(TMIN)
      CALL BGNMAT(IXDIM,IYDIM)
      CALL GETMAT(X,Y,T,NITEMS,0)
      CALL ENDMAT(TMAT,0)
C
C* * * SOLVE THE RATE OF HEAT TRANSFER * * *
C
      QSUM=0.0
      DO 70 I=1,IXDIM
      DO 50 J=1,IYDIM
      RQ=11.0000433 + 3.51919E-5*TMAT(I,J)
      -5.9562667E-6*TMAT(I,J)**2
      + 3.4129629E-8*TMAT(I,J)**3
      -4.740676E-11*TMAT(I,J)**4)*1000.
      XX=QUADX-FLOAT(IJ-1)*DX
      YY=QUADY-FLOAT(IJ-1)*DY
      RADIUS=SQRT(XX**2 + YY**2)

```



```

                                V=VEL*EXP(-RADIUS**2/WIDTH**2)
                                Q=RO*AHEA*V*.445*(TMAT(1,J)+273.16)
                                QSUM=QSUM+Q
60      CONTINUE
70      CONTINUE
      WRITE(6,80)QSUM
80      FORMAT(1X,'Q= ',F20.5)
C
C* * * * * PLUT THE CONTOURS * * * * *
C
      CALL CONMAK(TMAT,IXDIM,IYDIM,TINCR)
      CALL CONLIN(0,'SOLIDS','LABELS',1,10)
      CALL CONANG(90,0)
      CALL HASPLN(0.25)
      CALL CONTUR(1,'LABELS','DRAW')
      CALL HEIGHT(0.05)
      CALL RLMESS('EXP IC $',100,-59,-59)
      CALL DOT
      CALL GRID(1,1)
      CALL ENOPL(0)
      CALL DONEPL
      STOP
      END

```

## APPENDIX D

TABULATED DATA

TABLE 1

## ROTOMETER CALIBRATION

<u>% Flow</u>	<u>ml/s</u>	<u>Std Dev (ml/s)</u>
10	5.94	0.32
15	8.02	0.56
20	10.05	0.41
25	11.85	0.24
30	14.03	0.33
35	15.98	0.58
40	17.41	0.31
45	19.09	0.34
50	20.75	0.23
55	22.38	0.28
60	24.27	0.22
65	26.03	0.20
70	27.64	0.37
75	29.53	0.24

TABLE 2  
TEST RESULTS

Crossflow velocity:	.13 m/s
Nozzle flow rate:	11.85 ml/s (25%)
Nozzle inside diameter:	7.144 mm
Nozzle discharge velocity (mean):	29.558 mm/s
Nozzle temperature (mean):	41.8 °C
Ambient temperature (mean):	24.9 °C
Froude number:	14.8
Michaelis-Menter equation:	
Coefficient A:	2.64284325
Coefficient B:	1.03698254

<u>Plane</u>	<u>Y (mm)</u>	<u><math>\phi</math> (degrees)</u>	<u><math>\dot{Q}</math> (W)</u>
A	7.327	46	1.20
B	21.370	58	6.392
C	39.688	70	15.349
D	62.889	80	18.388
E	87.313	86	27.628

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